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ATMOSPHERIC DATA REQUIREMENTS FOR BATTLEFIELD OBSCURATION APPLICATIONS

JUNE 1980

Edited
By
E. H. HOLT

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US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report identifies current and future basic atmospheric data requirements--including estimates of sensing range, accuracy, and resolution--that are needed to assess and describe appropriate atmospheric effects on US Army weapons systems which involve the propagation of electromagnetic energy through the atmosphere.

The approach taken is user oriented, with the following types of users being identified: atmospheric modelers, weapons systems designers, weapons systems

20. ABSTRACT (cont)

developers, operational test and evaluation practitioners, and war game players. A section is also devoted to weather applications and possible needs of troop trainers and tactical decision makers, that is, field commanders.

Although some commonality of data requirements does exist across the spectrum of users, this report points out differences in individual user needs for atmospheric data to support Army electro-optical and near-millimeter wave weapons systems.

Comments are also included that address the all-important question as to what should constitute a minimum atmospheric data set that is adequate to support the total life cycle of electro-optical weapons systems from conception through deployment.

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EXECUTIVE SUMMARY

Coincident with the initial stages of the deployment of precision guided munitions (PGM), which will involve the outlay of billions of dollars, is an urgent concern about the performance of these PGM under "realistic" battle conditions. This concern is widespread in the Department of Defense and is echoed in the Army at the highest levels of the Army staff. Within the past 3 years the US Army Atmospheric Sciences Laboratory (ASL) has restructured its program around the problem of atmospheric effects on electro-optical (EO) weapons systems. Major efforts have been initiated to advance the state of the art in modeling these effects, using the concept of an EO Systems Atmospheric Effects Library of models covering all significant atmospheric scenarios (natural obscurants of all types and battlefield induced contaminants) at each of the important wavelengths--visible, near infrared (IR), mid IR, and far IR and near millimeter wave (NMMW). Complementing the modeling program has been an aggressive field measurements effort including a series of Dusty Infrared Tests (DIRT-I) and participation in other Army programs including the Smoke Week series sponsored by the Project Manager, Smoke/Obscurants. The dual purpose of the measurements program has been to fill gaps in the data base on atmospheric effects degrading EO systems performance and to provide information which can be used to assess the validity of the models.

To facilitate the introduction of atmospheric data and models into the activities of the segment of the Army community which is concerned with EO weapons systems, ASL hosted an atmospheric data requirements workshop in February 1979. The present report grew out of that workshop and a subsequent one, with an emphasis on the tactical problems of the commander in the field, held in February 1980. In conjunction with the workshops, two working papers were circulated and drew many valuable comments which have been incorporated into this report.

In October 1981 a follow-up workshop is planned to provide a forum for the discussion of this report and guidance for future work.

Chapter 1 of this report provides a background to the present high level of interest in this subject, and chapter 2 gives an overview of atmospheric effects on EO weapons systems. The overview describes the effects of all types of obscuring conditions on electromagnetic wave transmission in the atmosphere in different wavelength regions, factors which determine contrast transmission, the behavior of intentional smoke, and the significance of clouds and low visibility conditions. Work describing the sensitivity of EO systems to various atmospheric parameters is summarized although much more work needs to be done in this important area. The chapter ends with a summary of the viewpoints of a cross section of the Army community. The approach of soliciting views of involved members of the Army community is continued in subsequent chapters where the problems peculiar to each segment of this community are discussed. Thus, chapter 3 discusses the requirements of weapons systems designers and developers; chapter 4 presents the viewpoint of the operational test and evaluation community; chapter 5 discusses the introduction of atmospheric parameters into combat simulations and the requirements of war game players; and chapter 6 assesses the needs of the field commander both on the battlefield and in training exercises. Despite the February 1980 workshop in this area, the area remains undeveloped in comparison with the other topics, and continued emphasis is needed.

These user-oriented chapters reveal a great variety of needs for atmospheric data. Some needs reflect unique situations, and there is substantial duplication. To provide guidelines for the reader, whatever his special interest may be, a minimum set of atmospheric data for EO systems applications is described in chapter 7. This description is organized in three categories: a fundamental set of atmospheric parameters (which includes quantities like pressure and temperature) supplemented by a limited number of parameters which describe adverse weather in terms of particulate populations and a further increment to include battlefield induced contaminants. The definition of this minimum set enables the worker in this arena to critique whatever approaches he may encounter in terms of adequacy of treating atmospheric effects and also to reject overly complex approaches which include the use of an unnecessarily large number of atmospheric quantities.

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CHAPTER 1

INTRODUCTION
E. H. Holt

1.1 BACKGROUND

In February 1979 the US Army Atmospheric Sciences Laboratory (ASL) hosted a workshop in Las Cruces, New Mexico, to generate a perspective on how the various members of the Army user community incorporate atmospheric information into their activities. It was agreed at that time that ASL would write a report on atmospheric data requirements. To aid in this objective, a working paper was circulated in the Army community in August 1979 and suggestions were incorporated; a second working paper or progress report was circulated in the tri-service community November 1979. The replies showed that the needs of tactical users were ill-defined and a Tactical Coordinating Group (TCG), consisting of members of the Training and Doctrine Command (TRADOC) community, was convened and held a workshop in February 1980 in El Paso, Texas. The present report is based on the two working papers, the comments received from all segments of the Army community involved in this subject, and the deliberations of the two workshops.

1.2 WEATHER EFFECTS ON ELECTRO-OPTICAL SYSTEMS

The historical connection between weather and tactical military operations is well established and remains a topic of general interest.[1] However, the development of high technology weapons has resulted in a sensitivity to special properties of the atmosphere over and beyond those commonly associated with the weather. The orderly development of weapons systems with such sensitivities logically requires the prior evaluation of atmospheric effects followed by designs which minimize these effects. To the extent that "weather" in this specialized sense cannot be completely eliminated as a factor in systems performance, it is also important to develop the capability to predict the occurrence of limiting atmospheric conditions, so that the operational employment of sensitive systems will be made with maximum effectiveness. This capability, according to Dr. Ruth Davis, Office of Deputy Under Secretary of Defense for Research and Engineering (OUSDRE), is the true meaning of the phrase "all-weather" as applied to military systems.[2]

Limited success along these lines was indicated by Dr. Davis in her testimony to the US Senate[2] when she identified the ability to function in poor weather

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[1]J. Neumann, 1978, "Great Historical Events that were Significantly Affected by the Weather," Bull AMS, 56:1432-1437

[2]Ruth M. Davis, 1979, The Science and Technology Program, Report to US Senate, 96th Congress, Washington, DC

and under battlefield atmospheric conditions as a "primary risk area" in the deployment of precision guided munitions (PGM). A concern that inadequate attention has been paid to environmental effects in the past is also evidenced at high Army levels. It is only as the Army readies itself to deploy weapons, target acquisition, and surveillance systems depending upon electro-optical (EO) links in unprecedented numbers, that an urgent concern about their performance under realistic battlefield conditions has been expressed.[3] This concern is widespread in the Department of Defense (DOD) as evidenced by the recent call for a topical review of "all weather" capabilities by OUSDRE.[4]

The response to Army Vice Chief of Staff General Kerwin's message has been considerable. Detailed plans for field programs have been developed under the leadership of the Project Manager of Smoke and the US Army Materiel Development and Readiness Command (DARCOM) Smoke and Aerosol Steering Group.[5] Standards for describing and defining environmental conditions are being formulated.[6] Increasing realism with regard to environmental conditions is being introduced into the US Army war game simulations.[7] The laser designator/weapons systems simulation (LDWSS) of the US Army Missile Command has been expanded by including a battlefield obscuration option.[8]

This additional emphasis couples into the ongoing work which has been addressing this problem in the NATO arena under the OPAQUE project (optical

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[3]Kerwin, 1977, The Use of Realistic Battlefield Environmental Conditions Throughout the Army, DAMO-RQS, Headquarters, US Army, Washington, DC

[4]Ruth M. Davis, 1979, Topical Review of "All Weather" Capabilities, Office of the Under Secretary of Defense (R&E), Washington, DC

[5]DARCOM, 1979, Smoke and Aerosol Steering Group Technology Base and Testing Plans, US Army, Office of Project Manager Smoke, Adelphi, MD

[6]R. G. Humphrey and W. H. Pepper, 1979, Standards for Environmental Conditions (Preliminary), Harry Diamond Laboratories, US Army Electronics Research and Development Command, Adelphi, MD

[7]H. E. Hock, 1978, Degraded Environment Modeling in High Resolution Ground Combat Simulations, (U), SECRET, CAA-TP-78-2, US Army Concepts Analysis Agency, Bethesda, MD

[8]R. E. Alongi, R. E. Yates, M. V. Maddox, and J. L. Shady, Jr., 1979, BELDWSS - An Extension of LDWSS to Treat Battlefield Obscurants, US Army Missile Research and Development Command, Special Report T-79-20, Redstone Arsenal, AL

atmospheric quantities in Europe),[9] with particular attention being paid to optical atmospheric characteristics in West Germany.[10] [11] It also reinforces the concern of the environmental science community as demonstrated, for example, by the workshop sponsored by Captain Ruggles (OUSDRE) at the Air Force Academy in 1976.[12]

There is evidence that in the future environmental effects will be considered in the early stages of new technology developments, indicating that an important lesson has been learned.[13]

1.3 ISSUES RAISED AT THE 1979 ATMOSPHERIC DATA REQUIREMENTS WORKSHOP

The following concepts were expressed at the Atmospheric Data Requirements Workshop:[14]

Routine climatological data must be supplemented to provide predictions of EO systems performance, but there is no concensus on how to do this.

The meteorological parameters used need to be standardized so that results obtained by different investigators can be compared. This standardization requires common acceptance of what should be measured as well as how the measurements should be made. More work needs to be done in both areas.

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[9] R. W. Fenn, 1978, A Measurement Program on Optical Atmospheric Quantities in Europe, AFGL-TR-78-0011, US Air Force Geophysics Laboratory, Hanscom Air Force Base, MA

[10] R. G. Pinnick, D. L. Hoihjelle, G. Fernandez, E. B. Stenmark, J. D. Lindberg, G. B. Hoidale, and S. G. Jennings, 1978, "Vertical Structure in Atmospheric Fog and Haze and Its Effects on Visible and Infrared Extinction," J Atmospheric Sci, 35:2020

[11] R. E. Roberts, 1976, Atmospheric Transmission Modeling: Proposed Aerosol Methodology with Application to the Grafenwöhr Atmospheric Optics Data Base, Institute for Defense Analyses, Arlington, VA, p 1225

[12] K. W. Ruggles, 1977, Proceedings of the Optical-Submillimeter Atmospheric Propagation Conference, Office of the Director of Defense Research and Engineering, Washington, DC

[13] Ruth M. Davis, 1979, Meteorological Measurement Program for High Energy Laser Testing at WSMR, Office of the Under Secretary of Defense (R&E), Washington, DC

[14] J. T. Hall, 1979, Atmospheric Data Requirements Workshop 13-14 February 1979, ASL Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

Atmospheric data should be collected in a way that would allow correlations to be made among the variables to be evaluated. In general, not only two-way correlations but also multifactor correlations and autocorrelations are potentially significant in weapons performance modeling.

Each user of atmospheric information is motivated to identify a minimum set of atmospheric quantities which will be sufficient to solve his problem.

1.4 ATMOSPHERIC MODELS

1.4.1 Size Considerations

All users of atmospheric data in the context of this report use the data as input to some type of model. The type of model involved has a large effect on the amount and variety of atmospheric data needed.

The tactically oriented modeler, for example the war gamer, includes an atmospheric effects model as a very small part of a large computer simulation. Severe restraints are imposed on the quantity of computing which can be assigned to describing atmospheric effects. In this case the need is great to identify the minimum essential atmospheric information which will reasonably account for the atmospheric effects.

At the other extreme is the atmospheric scientist whose concern is to build a model which will advance the understanding of atmospheric effects on EO systems. The emphasis here is on the comprehensiveness and adequacy of the knowledge of atmospheric quantities. As a result of the atmospheric scientists' work, shortcuts can be evolved which will enable the needs of the tactically oriented user to be satisfied with simplified algorithms requiring a minimum of atmospheric data.

Other users of atmospheric data stand in an intermediate position. Weapons systems designers require models which properly account for the variation of atmospheric effects with the wavelength of the system. They are concerned with the operation of a new design in different climates. Weapons systems developers, concerned with system feasibility and evaluation, need enough atmospheric data during field measurements to input to an intermediate size atmospheric model which will be adequate to explain the atmospheric effects which occur.

1.4.2 Types of Atmospheric Models

Realistic battlefield atmospheric models have been constructed to handle the realistic battlefield problem.[15] These models address natural and battlefield-contaminated atmospheres and may be classified as clear atmosphere models, adverse weather models, dust models, and smoke models.

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[15]L. D. Duncan, R. C. Shirkey, R. A. Sutherland, E. P. Avara, H. H. Monahan, 1979, Electro-Optical Systems Atmospheric Effects Library Vol I: Technical Documentation, ASL TR-0047, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

Anticipated future models include composites of these models and the roles of terrain and vegetation. Research is underway to develop simpler and smaller models on the one hand and to develop larger models which might improve the agreement between model predictions and measured results on the other hand.

Good clear atmosphere models currently exist. Additional work is required for improved modeling of battlefield atmospheres. Adverse weather models describe low natural visibility conditions and effects brought about by increased aerosol loading of the atmosphere by hygroscopic particles. Haze, mist, and fog which consist of spherical water-containing particles are included. Connections between particle size distributions and extinction coefficient can be calculated (using Mie theory) as a function of the wavelength of interest. However, nonspherical particles such as dust and snow present special difficulty, and new approaches are being explored to calculate their effects. Dust obscuration depends upon soil type, soil conditions, and the source which causes the dust to enter the atmosphere. The refractive index, size distribution, and particle shape affect the extinction, but the theory is more approximate. Smokes exist in particulate form and their extinction can be calculated from the Mie theory when the relative humidity is known. Both dust and smoke obscuration may be compounded by thermal plumes imbedded within the cloud.

Since the Army also has operational interest in coastal and island locations, models that incorporate marine aerosols of oceanic origin, for example, salt nuclei, must be included in adverse weather descriptions. Valuable data input to such models should be forthcoming from the US Navy's EO Meteorology (EOMET) Program.

1.5 UNITS AND DIMENSIONS

Throughout this report the reader will note usage of units and dimensions which are not entirely of the metric system and in some instances are a mixture of English and metric systems. The position of the authors of this report is to show data requirements and listings exactly as provided by respondents of queries for this information. Also, in the United States, environmental measurement and observation practices have not yet fully converted to the metric system and this is reflected in data sources.

1.6 ORGANIZATION OF THE REPORT

The report begins with an overview of atmospheric effects on EO weapons systems (chapter 2). The effects of obscurants on transmission are discussed along with factors influencing contrast transmission; parameters involved in the behavior of smoke, clouds, and air operations; and visibility. Methods of measuring transmission and its surrogates are mentioned briefly. Work describing the sensitivity of EO systems to various atmospheric parameters is summarized. The chapter ends with the viewpoints of a cross section of the Army community which needs atmospheric data in the performance of its mission.

Chapters 3 through 6 describe the atmospheric data needs of the major segments of the Army community. Weapons systems designers and developers are covered in chapter 3 and the operational test and evaluation community in chapter 4. The introduction of atmospheric parameters into combat simulations and the requirements of war game players are treated in chapter 5. The needs of the field commander both on the battlefield and in training exercises are assessed in chapter 6.

These user-oriented chapters reveal a plethora of apparent needs. Some of the needs reflect unique situations, and there is a substantial duplication. To simplify the situation and provide guidelines for the reader, whatever his vested interest, chapter 7 proposes a minimum set of atmospheric data for EO system applications. These data are organized in three categories: a fundamental set including pressure, temperature and the like; an adverse weather increment; and a battlefield induced contaminants (BIC) increment.

1.7 FUTURE PLANS

This report will form the basis of a follow-up workshop planned for October 1981. At this time we will invite the TRADOC community and others to critique the present effort and make suggestions for the future direction of this type of work.

CHAPTER 2

ATMOSPHERIC EFFECTS ON EO WEAPONS SYSTEMS AND RELATED ATMOSPHERIC PARAMETERS

H. H. Monahan

2.1 ENVIRONMENTAL EFFECTS AS DETERMINANTS OF DATA REQUIREMENTS[16]

Fog, clouds, rain, snow, hail, smoke, dust, and water vapor all degrade target acquisition and EO weapons delivery systems. Stable large-particle fogs, clouds, rain, and snow cause substantial degradation of infrared (IR) systems performance. Haze, some forms of smoke, small-particle fogs, and water vapor cause less but still significant degradation. In the microwave region, rapid changes in water vapor content of the air over short distances can cause strong beam refraction that results in beam trapping (ducting) and the creation of null coverage zones. Three terms are used to describe water vapor content: (1) absolute humidity refers to the amount of water vapor per unit volume of air, (2) relative humidity is the ratio of the actual amount of water vapor in the air to the maximum amount it can hold at a given temperature and pressure, and (3) precipitable water is the equivalent thickness of a vertical column of water vapor if it were condensed into liquid water. Certain types of particles in the air have an affinity for water vapor and become coated with layers of liquid water at relative humidities well below 100 percent. If a substantial number of these particles are present, relative humidity values will have a larger than normal influence on the attenuation of IR radiation. Microwave signals, particularly those in the regions of 10, 34, and 95 gigahertz frequencies, pass nearly unimpeded through all but the heaviest fogs, clouds, and precipitation.

IR systems can be used at night because they sense emitted radiation rather than reflected radiation; however, IR radiation is absorbed by water. Additionally, materials heat and cool at different rates and emit with different efficiencies. Thus, different materials may radiate different amounts of energy although they may be at the same temperature.

The apparent contrast between a target and its surroundings will determine the distance to which a target can be acquired by an appropriate sensor at the limit of the acquisition range. At visible wavelengths and during daylight hours, the differentiating characteristics are brightness, color, and texture. Brightness (or luminance), the most useful characteristic for determining contrast, is a measurable quantity which depends upon the amount of illumination provided, the ratio of the reflected energy to the incident energy, and for most objects, the angle of view. The illumination (or light level) is a function of solar altitude, with or without clouds, and the phase of the moon if night illumination is considered. Energy reflected from either a target or its background is attenuated (absorbed or scattered) by atmospheric constituents and affects beam transmittance which is defined as the ratio of energy arriving at the sensor from a target to the energy originally

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[16] W. K. Crandall, 1977, Meteorology Analysis of Offensive Air Support, ASD-TR-77-51, US Air Force Aeronautical Systems Division, Wright-Patterson Air Force Base, OH

radiated along the path toward the sensor from the target. Path luminance, the energy which is scattered into the target/sensor LOS by atmospheric particles, is a function of the size, composition, and number density of those scattering particles, the wavelength of the transmitted light, the direction toward which the observation is directed, and the direction from which the illumination is incident.

The intentional use of smoke as a battlefield obscurant, coupled with the dust raised by the movement of many vehicles over dry terrain and the effluents from numerous munitions explosions, can cause visibility problems that adversely affect the use of EO target acquisition devices. To describe these effects, information would have to be obtained about particle amount, size, distribution and composition, coagulation rate, relative humidity effect, fallout and rainout rates, some measure of the rate of atmospheric mixing, mixing depth, stability, wind direction and windspeed, and wavelength dependency of scattering and absorption coefficients.

However, for short-term effects, a qualitative measure of the effectiveness of battlefield smoke as a screening agent can reasonably be assessed by considering atmospheric stability (Pasquill stability categories) and mixing depth. Being a function of windspeed, incoming solar radiation, and cloud cover, Pasquill stability categories relate to the rate at which smoke, or another pollutant, is dispersed into the atmosphere; that is, instability leads to rapid dispersion and stability leads to slow dispersion. The mixing depth is the layer above the ground surface into which a pollutant could be expected to disperse over a period of time. Generally, shallower mixing depths occur with stable atmospheric conditions.

Air operations are critically influenced by the amount and height of the cloud cover existing between the operational altitude and the ground. Primarily, the presence of clouds interrupts the continuity of the target acquisition process, but the shadow of clouds passing over a target area also affects the level of illumination and may render the target indiscernible from its background. A uniform cloud coverage of zero to two-eighths below an operational level will generally allow successful completion of an air-to-ground mission, assuming limited maneuverability. A coverage of 6/8 to 8/8 will likely negate the mission, while the occurrence of 3/8 to 5/8 of cloud produces uncertainty of successful mission completion.

Horizontal visibility is defined as the greatest distance, during the day, that a dark object can be recognized against the horizon sky; at night, it is the greatest distance from which a moderately intense (preferably unfocused) light can be seen. Unfortunately, the reporting of the prevailing visibility in weather observations is subject to two different viewpoints; that is, the World Meteorological Organization requires the reporting of the minimum visibility observed as the prevailing visibility, while in the United States prevailing visibility is defined as the greatest horizontal visibility existing over one-half or more of the horizon circle, not necessarily continuous.

Furthermore, prevailing visibility, which considers only the greatest distance that an object on the ground can be detected by an observer, may not be representative of the slant range visibility (or seeability), which is the greatest distance that an object on the ground can be detected, recognized, or identified from a point some distance above and away from the object. A turbid

atmosphere will decrease sensor seeability from the air. Slant range visibility may be greater or less than horizontal visibility because the visibility restricting medium is not necessarily distributed uniformly in space and time.

The dominant atmospheric parameter affecting EO systems performance is the atmospheric transmission at the wavelength of operation. In practice this parameter is usually measured by a double-ended instrument, the transmissometer, with both terminals being at ground level. Slant path measurements can be made by mounting one terminal on a tower. An alternative approach is to calculate the transmission from measurements of atmospheric particulates including the mass loading, size distribution, and refractive index. In this case information about the vertical structure can be obtained from instrumented aircraft[17] or balloon-borne instruments.[10]

Several atmospheric quantities have been shown to be effective in predicting the variation in atmospheric transmission. Roberts[11] and Roberts and Seekamp[18] have shown that liquid water content (LWC), or volume density of H_2O, is a valuable predictor of IR extinction and sidesteps the need to determine aerosol size distributions under conditions of limited visibility. Lutomirski[19] has introduced the total atmospheric mutual coherence function as a tool for analyzing the performance of EO systems due to the combined effect of molecules, turbulence, and aerosols. The practical value of these quantities is tied to progress in instrumentation which will make them readily and reliably determinable.

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[17]G. B. Matthews et al, 1978, Atmospheric Transmission and Supporting Meteorology in the Marine Environment, US Navy, Pacific Missile Test Center, Point Mugu, CA

[10]R. G. Pinnick, D. L. Hoihjelle, G. Fernandez, E. B. Stenmark, J. D. Lindberg, G. B. Hoidale, and S. G. Jennings, 1978, "Vertical Structure in Atmospheric Fog and Haze and Its Effects on Visible and Infrared Extinction," J Atmospheric Sci, 35:2020

[11]R. E. Roberts, 1976, Atmospheric Transmission Modeling: Proposed Aerosol Methodology with Application to the Grafenwöhr Atmospheric Optics Data Base, Institute for Defense Analyses, Arlington, VA, p 1225

[18]R. E. Roberts and L. N. Seekamp, 1979, Infrared Attenuation by Aerosols in Limited Atmospheric Visibility: Relationship to Liquid Water Content, Institute for Defense Analyses, Arlington, VA, p 1394

[19]R. F. Lutomirski, 1978, "Atmospheric Degradation of Electro-Optical System Performance," Appl Opt, 17:3915-3921

2.2 SENSITIVITY OF EO SYSTEMS PERFORMANCE TO METEOROLOGICAL FACTORS

Let us first consider the sensitivity of EO systems performance predictions to uncertainties in measured values of meteorological parameters. Snyder[20] has evaluated the sensitivities for systems operating in the 3- to 5-micrometer and 8- to 12-micrometer wavelength range. Under conditions of good visibility, he considers temperature and relative humidity to be the most important meteorological parameters. The measurement uncertainty is the maximum associated with conventional radiosonde observations. The results can be summarized as follows:

Meteorological Parameter	Measurement Uncertainty	Uncertainty Effects On System Performance (percent) 3μm-5μm	8μm-12μm
Temperature	±2°C	2	10
Relative humidity	±10%	3	10
RMS sum of temperature and relative humidity	NA	5	15

In comparison, the Range Commanders Council/Meteorology Group Document 110-77, Meteorological Data Error Estimates,[21] indicates that surface-based measurements of temperature can be made within 0.6°C and relative humidity within 3 percent dependent upon temperature, while radiosonde-measured values of the same parameters can be obtained within 0.8°C and 10 percent dependent upon altitude or temperature, respectively.

Aerosol effects are of a wide variety, but the common effect is the degradation of visibility. Snyder takes the surface visibility as the key meteorological parameter to account for aerosol effects. He considers two values of visibility, moderately low (4 kilometers) and moderately high (20 kilometers). Two relative uncertainties were considered, 20 and 50 percent.

A new problem arose in this case because of the plurality of models purporting to account for the effects of aerosols on transmission. Several models were used to avoid drawing model dependent conclusions. However, the only agreement between the models was that the uncertainties in visibility at the lower

[20]F. P. Snyder, 1978, The Effects of Meteorological Uncertainties on Electro-Optical Transmittance Calculations, Technical Note 440, Naval Ocean Systems Center, San Diego, CA

[21]Range Commanders Council/Meteorological Group, Document 110-77, Meteorological Data Error Estimates, Meteorological Group, Inter-Range Instrumentation Group, Range Commanders Council, White Sands Missile Range, NM

visibility considered (4 kilometers) are more important than similar uncertainties at the higher visibility (20 kilometers). Whether uncertainties in visibility were more important at the shorter wavelength (3 to 5 micrometers) than at the longer wavelength (8 to 12 micrometers) or vice versa depended upon the aerosol model used.

Another important type of sensitivity study has been performed by Jennings et al.[22] Mie theory was used to determine the effect of the range of values of the real and imaginary parts of the complex index of refraction of atmospheric particulate material (aerosols) which occurs in practice on volume extinction and absorption coefficients. Changes in extinction by up to an order of magnitude were found for realistic variations in refractive index in the wavelength range 2 to 10 micrometers. Similar changes in extinction are caused by variations in particle size distribution with absorption less dependent on size distribution than extinction.

Sensitivity studies of the types conducted by Snyder[20] and Jennings[22] establish the significance of various atmospheric parameters in EOMET and the accuracy with which they must be known.

2.3 SELECTED USER VIEWPOINTS ON DATA REQUIREMENTS

To obtain a cross section of assessments of atmospheric data requirements, six US Army agencies, having a variety of responsibilities and concerns in the area of atmospheric effects on EO weapons systems, were asked to describe their requirements for atmospheric data. The Project Manager, Smoke/Obscurants represents a focal point in the Army for determining environmentally caused performance degradation of Army weapons systems. The Combat Developments Experimentation Command (CDEC) and the Operational Test and Evaluation Agency (OTEA) are concerned with weapons test under realistic battlefield conditions. The Aviation Research and Development Command (AVRADCOM) is involved in the effect of meteorological conditions on EO airborne systems. The Night Vision and Electro-Optics Laboratory (NVEOL) needs to be able to assess the performance of IR sensors in a wide range of environments, and the Army Materiel Systems Analysis Agency (AMSAA) is concerned with realistic weapons systems performance analyses.

The Project Manager, Smoke/Obscurants identifies the need for information on particle size distribution and aerosol concentrations as functions of time along multiple lines of sight (LOS) from various remote locations. Information is also needed on the vertical structure of the atmosphere in terms of visibility, particle size, and particle number density. Measurements are

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[22]S. G. Jennings, R. G. Pinnick, and H. J. Auvermann, 1978, "Effects of Particulate Complex Refractive Index and Particle Size Distribution Variations on Atmospheric Extinction and Absorption for Visible Through Middle IR Wavelengths," Appl Opt, 17:3922

[20]F. P. Synder, 1978, The Effects of Meteorological Uncertainties on Electro-Optical Transmittance Calculations, Technical Note 440, Naval Ocean Systems Center, San Diego, CA

required of atmospheric pressure, relative humidity, solar brightness, and obscured sky conditions, for example, estimated cloud cover and cloud height, as well as measurements of wind direction, windspeed, and temperature at the recommended heights of 2, 4, 8, 16, and 32 meters. A requirement exists for transmissivity information at 0.4 to 0.7, 1.06, 3, 4, 9 to 11, and 11 to 13 micrometers for various meteorological conditions.[23]

Multidirectional visibility and multispectral slant path visibility are required by CDEC to provide the overall spatial and temporal resolution of clouds and specific point-to-point obscuration. There is an interest in the climatologies of various possible test sites for properly documenting the simulation of realistic battlefield conditions that employ the precise placement of smoke and artillery munitions.[24]

OTEA states that meteorological measurements are needed in a "dirty battlefield" (DB) environment that provide correlative indicators of the transmissivity of the medium at the time that LOS exists along the predicted trajectory of the weapon between the launch platform and the target.[25]

AVRADCOM refers to the need for information of environmental effects on sensors operating from 0.4 micrometer to 3.2 millimeters. Since their systems are airborne, a requirement exists for slant range and altitude dependent data.[26]

NVEOL requires considerable meteorological data with increased accuracies to support modeling activities. These activities include models addressing natural atmospheres and active battlefield obscurants, target signature modeling, REBTAM development, and near millimeter wave (NMMW) modeling.[27]

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[23] Letter, 13 April 1979, DA, PM-Smoke, DRCPM-SMK-T, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

[24] Letter, 5 April 1979, US Army Combat Developments Experimentation Command, ATEC-PL-M, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

[25] Letter, 10 May 1979, US Army Operational Test and Evaluation Agency, CSTE-ED, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

[26] Letter, 16 May 1979, US Army Aviation Research and Development Command, DECPM-RPV, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

[27] Letter, 27 April 1979, US Army Night Vision and Electro-Optics Laboratory, DELNV-VI, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

AMSAA indicates a particular concern for guided munitions, for example, COPPERHEAD, involving the distribution of clouds. A simplified approach to the solution of this problem uses cloud-free and clear LOS probabilities which should, at a minimum, be considered as functions of altitude, elevation angle, location, month, and hour.[28]

Considerable meteorological data of interest in the development and operational testing of EO and NMMW systems will require high temporal and spatial resolution; that is, the data must be collected within minutes and within a kilometer of the occurrence of the event, particularly when obstructions to vision exist. Simultaneous conventional meteorological measurements and transmission measurements at wavelengths of interest are currently essential to provide an understanding of systems performance. Although many atmospheric parameter specifications are not firm requirements, table 2-1 is a composite of meteorological data requirements stated in letters to ASL and indicates the variety of atmospheric quantities which affect the performance of EO systems.

[28]Letter, 21 December 1979, US Army Materiel Systems Analysis Activity, DRXSY-GS, subject: "Comments on Atmospheric Data Requirements for Battlefield Obscuration Applications"

TABLE 2-1. COMPOSITE OF METEOROLOGICAL DATA REQUIREMENTS

Parameter	Generalized Data Specifications: Range	Accuracy	Vertical Resolution	Extreme Data Specifications: Range	Accuracy	Vertical Resolution
Cloud Amount	0/8-8/8	1/8				
Cloud Type	All types below 10 km above ground level (AGL)					
Cloud Base Height	0-1.5 km AGL	±30 m	30 m	0-5.0 km AGL	±10 m	10 m
	1.6-3.0 km	±150 m	150 m			
	3.1 km	±300 m	300 m			
Cloud Top Height	0-5.0 km AGL	±100 m	100 m	0-10.0 km AGL	±30 m	
Multicloud Layers Distribution	0-5.0 km AGL	±100 m	100 m	0-5.0 km AGL	±30 m	
Heights Separation Thickness Percent Coverage, Each Layer Distribution of Cloud Holes						
Horizontal Visibility	0-23 km AGL	±100 m AGL ≤ 23 km	10 m	0-5.0 km	±10 m	1 m ≤ 50 m AGL*
	23-60 km AGL	±1000 m ≥ 23 km				30 m ≤ 600 m AGL*
	0-5 km*	±1 m ≤ 30 m AGL*				
		±5 m ≥ 30 m AGL*				
Slant Path Visibility	0-23 km AGL	±100 ≤ 23 km	10 m	0-5.0 km	±10 m	1 m ≤ 50 m AGL*
	0-5 km*	±1 m ≤ 30 m AGL*				30 m ≤ 600 m AGL*
Temperature	-50°C to 50°C	±1°C	100 m	-70°C to 60°C	±0.5°C	1 m ≤ 10 m AGL
					±0.2°C Near Freezing	10 m ≤ 100 m AGL
Dew Point Temperature	-50°C to 50°C	±1°C	100 m	-70°C to 60°C	±0.5°C	1 m ≤ 10 m AGL
						10 m ≤ 100 m AGL
Relative Humidity	0-100%	±1%	100 m			10 m ≤ 100 m AGL
Absolute Humidity	0-30 g/m^3	±5%	100 m			10 m ≤ 100 m AGL
Pressure	915-1090 mbar	±0.3 mbar	10 m ≤ 100 m AGL			
Windspeed	0-100 km/h	±2 km/h	100 m	0-40 m/s	±0.5 m/s	5 m ≤ 50 m AGL
						25 m > 50 m AGL
Wind Direction	0-360	±10°	100 m			5 m ≤ 50 m AGL
						25 m ≥ 50 m AGL
Wind Gust	Up to 100 km/h	±5°	100 m			5 m ≤ 50 m AGL
Spread						25 m > 50 m AGL

*Army Aviation Requirement

TABLE 2-1. (CONT)

Parameter	Generalized Data Specifications: Range	Accuracy	Vertical Resolution	Extreme Data Specifications: Range	Accuracy	Vertical Resolution
Turbulence (C_n^2)	0-10 km AGL	±20%				
Stability Index	Pasquill	A-F categories				
Precipitation Amount	0-100 in	±0.1 in				
Precipitation Type	As reported					
Total Snow Depth	0-100 in	±0.5 in				
State-of-Ground	Codes 0-9 as reported					
24-hr Max Temperature	To 60°C	±1°C			0.5°C	
24-hr Min Temperature	To -60°C	±1°C			0.5°C	
Air Mass Type	Origin, e.g., arctic, polar, tropical, maritime, continental					
Air Mass Trajectory	Warm and cold air masses					
Liquid Water Content	0.002-1 g/m^3	±5%	100 m			10 m ≤ 1 km AGL
Liquid Water Drop Size Distribution	3μm-3000μm	±1μm	100 m	Up to 10000 m		10 m ≤ 1 km AGL
Aerosol Concentration	1-30 mg/m^3	±0.1 mg/m^3	100 m			10 m ≤ 1 km AGL
Aerosol Particle Size	0.2μm-1500μm	±1μm	100 m			10 m ≤ 1 km AGL
Industrial Smoke Concentration	0-40 mg/m^3	±0.1 mg/m^3	10 m ≤ 500 m AGL 100 m > 500 m AGL			
Haze	0-10 km	±0.1 km	100 m			
Mist (mass loading)	1-100 mg/m^3	±1 mg/m^3	100 m			
Dust (mass Loading)	0-200 mg/m^3	±1 mg/m^3	10 m ≤ 100 m AGL			
	10μm-300μm radius	1μm	100 m > 100 m			
Fog	0-10 km		10 m ≤ 100 m AGL 100 m > 100 m			
Fog Character	Radiation, advection, etc.					
Rate of Precipitation:						
Drizzle	To 1 mm/h	±10%				
Rain	To 50 mm/h	±1 mm/h			±0.1 mm/h	
Snow	To 50 mm/h	±1 mm/h		To 100 mm/h	±0.1 mm/h	
Thunderstorms	To 300 mm/h	±10 mm/h				
Hail Size	5-20 mm radius	±5%		1 cm diameter		
Lightning	Candlea units					
Icing Types	As reported, e.g., clear, rime, frost					
Icing Intensity	As reported					
Height of Mixing Layer	0-5 km	±50 m				
Mean Temperature Lapse Rate	0-5 km	°C/km				
Mean Vertical Pressure Gradient	0-5 km	mbar/km				

TABLE 2-1. (CONT)

Parameter	Generalized Data Specifications Range	Accuracy	Vertical Resolution	Extreme Data Specifications Range	Accuracy	Vertical Resolution
Snow Cover						
Density	0-0.6 g/cm^3	$\pm 0.01\ g/cm^3$		0-0.91 g/cm^3	$\pm 0.01\ g/cm^3$	
Water Equivalent	0-10% (of snow depth)	$\pm 1\%$				
Temperature	$-40^{\circ}C$ to $0^{\circ}C$	$\pm 0.5^{\circ}C$ $\pm 0.2^{\circ}C$ near freezing				
Grain Size	50μm-3000μm		To 1.5 mm			
Other Parameters						
Cloud-Free Line of Sight	0-5 km	$\pm 5\%$				
Clear Line of Sight	0-5 km	$\pm 5\%$				
Insolation		$Watts/m^2$				
Illumination	10^{-6} to 10^4 fc	$\pm 5\%$				
Atmosphere Sky-Ground Ratio						

Transmission at 0.2μm-0.4μm, visible, 0.8μm-2.5μm, 3μm-5μm, 8μm-14μm, 100μm-3 mm wavelengths

and 10, 35, 94 GHz frequencies

Target imaging measurements at visible, 3μm-5μm, and 8μm-14μm wavelengths

CHAPTER 3

THE NEEDS OF WEAPONS SYSTEMS DESIGNERS AND WEAPONS SYSTEMS DEVELOPERS

S. F. Kubinski

3.1 INTRODUCTION

As indicated by Nelson et al,[29] the process by which a weapon system is conceived, designed, tested, and acquired usually receives its first formal impetus at the time a "statement of need" is issued. The "statement of need" will describe the desired system capability, the concept of operation, and the environment in which the system must operate.

Designing suitable military hardware is an engineerng problem. The ways in which the natural environment affects various types of military hardware are relatively well understood by hardware designers. A design analysis should begin with a definition of a "standard set" of atmospheric conditions that reflect the kind of conditions that might typically be encountered. However, since hardware developers many times are interested primarily in showing the capability of a piece of hardware, there is the possibility that many kinds of unfavorable environmental conditions simply may not be addressed.

As the system design matures, a development test and evaluation program is planned and executed. The basic thrust of the development test and evaluation program is to determine if the system meets design specifications. It is the responsibility of the test director to design experiments and collect appropriate test data to show whether or not the design specifications have been met.

The needs of EO weapons systems designers and developers require that "standard meteorological measurements" with conventional instruments be made in conjunction with measurements of nonstandard parameters such as transmissivity, absorption, turbulence (mechanical and thermal), gas composition (CO, C_2O, NO_x), aerosol size, density and distribution (both natural and battlefield induced), precipitation type, and rain rate, requiring special instruments and data collection techniques.

The standard meteorological measurements refer to the type of meteorological measurements routinely made for synoptic weather observations, for example, temperature, pressure, humidity, windspeed, and wind direction. Shortfalls in present capabilities to provide the required nonstandard measurements need to be overcome by development and/or acquisition of new meteorological and optical, aerosol, and gas measuring instrumentation and techniques to meet expanded EO requirements.

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[29] R. J. Nelson et al, 1980, Atmospheric Data Requirements for US Army Electro-Optical Systems Applications, Final Report, SAI-166-927-001, Science Applications, Incorporated, Electro-Optics Analysis Division, Ann Arbor, MI

Baseline measurements affecting NMMW system components and development are needed. Propagation data with associated climatology characterization of dust, haze, fog and rain, vertical structure for fog and haze, and slant path measurements are required to resolve anomalies. Specifically needed are: EO spectral data for natural and perturbed atmospheres, atmospheric effects which degrade forward looking infrared (FLIR) operations, and tactical smoke characterization and its effects.[30]

3.2 ATMOSPHERIC DATA REQUIREMENTS

The following needs of the US Army Missile Research and Development Command (MIRADCOM), as a weapons systems designer, have been enumerated:[31]

- Mesoscale weather information for specific battle zones
- Aerosol properties
- Aerosol models - predict propagation at different wavelengths
- Multiple scattering effects
- Observations in different geographical locations
- Aerosols - smoke, dust
- Contingency tables expressing joint probabilities of:
  - Visibility and cloud ceiling
  - Relative humidity and temperature
- Clear LOS data
  - Ground to 1500 feet AGL - helicopter operations
  - Terrain effects at specific locations
- Statistics of temperature inversions
- Data relating to the dissipation of obscurants

During test and evaluation of EO devices, weapons systems developers need a comprehensive program to measure and document the structure of the atmosphere. The atmospheric data requirements of the test and evaluation group are more demanding than those of the tactical users and training communities, so that any measurement program will be expanded during initial testing phases to encompass as many of the desirable parameters as possible. Table 3-1 is a list of such parameters.

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[30] R. S. Rohde, 1979, "Near Millimeter Wave Fourier Transform Spectrometer Experiment," Atmospheric Data Requirements Workshop, 13-14 February 1979, ASL Internal Report, J. T. Hall, ed, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[31] D. Stewart, 1979, "MIRADCOM (MICOM) Atmospheric Requirements," Atmospheric Data Requirements Workshop, 13-14 February 1979, ASL Internal Report, J. T. Hall, ed, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

TABLE 3-1. DATA FOR TEST AND EVALUATION

Parameter	Typical Accuracy*
Windspeed	±0.5 m/s
Wind direction	±5°
Temperature	±0.1°C
Pressure	±0.1 mbar
Relative humidity	±2%
Sky cover	±10% of actual
Ceiling	±30 m
Particle size distribution	20%
Particle number density	20%
Type of precipitation	fog, rain, snow, hail
Visibility†	0-1 km ±10 m
Condensation nuclei	20%
Liquid water content	10%
Precipitation rate	±1 mm/h
Visible transmission	10%
1.06-micrometer transmission	10%
3- to 5-micrometer transmission	10%
8- to 12-micrometer transmission	10%
Millimeter wave transmission	10%
Surface albedo	10%
Sky-to-ground ratio	10%
Height of inversion	±10 m
Thermal turbulence	20%
Mechanical turbulence	20%
Extinction coefficient	20%
Scattering coefficient	20%
Illumination level	5%
Cloud-free LOS	5%
Gas concentrations	10%
Solar radiation	20%
Solar and lunar azimuth and elevation	10°
Refractivity	--
Contrast transmission	--

*Accuracy requirements will vary with test and evaluation plans and operational test scenarios.

†Visibility, as recorded for standard synoptic (airways type) observations, is not a measurement but a sensory (i.e., noninstrumental) observation. Finding an instrumental measurement equivalent to this human observation of visibility is no simple task. There is a need to extend the meaning of visibility to those portions of the spectrum in which EO systems operate.

3.3 UTILIZATION OF BASIC ATMOSPHERIC QUANTITIES IN EO SYSTEMS EVALUATION

General uses common to all atmospheric data are for:

Describing the state of the atmosphere during test and evaluations;

Adjusting tests to "standard" conditions;

Updating data banks; and

Identifying environmental anomalies affecting EO systems.

Specific uses of the principal atmospheric quantities are as follows:

3.3.1 Density

Density is used to determine atmospheric transmission and emissions of optical and IR radiation. When not measured directly, density is computed from temperature, pressure, and humidity measurements.

3.3.2 Temperature, Humidity, Pressure, Wind, Visibility

Measurements of these standard parameters are used in clear-air and thermal-turbulence studies and specification of atmospheric stability and thermodynamic structure in the atmosphere. They are used to correlate meteorological data with recognition range data from EO imaging systems, with laser spot location and with EO guidance sensor tracking capability under varying atmospheric conditions.

Temperature and humidity are also used in computation of density and index of refraction where these are not measured directly. The vertical temperature gradient in the boundary layer (generally 2 to 16 meters) indicates that atmospheric thermal stability and wind variability are also important in describing the diffusive power of the atmosphere on such effluents as countermeasures (CM) smoke. Predictions of this gradient are required along with wind predictions for estimating hazard distance for plume (cloud) travel of a toxic spill and determining smoke concentration and diffusion.

Water vapor is an important absorber in certain spectra, and absolute humidity is needed for studies of linear and nonlinear propagation.

Windspeed and wind direction are needed to determine CM smoke and chaff diffusion and dispersion. Fine-scale wind measurements are needed to determine effects of ventilation (for example, pointing accuracy versus laser spot location); vertical shear is needed for Richardson's number calculations; vertical component of wind is used in heat flux and stability calculations and for test go/no-go decisions.

The visibility provides a primitive sensor (that is, noninstrumental) measure of atmospheric clarity; it attempts to relate in one number the complex relationships between target and its contrast, atmosphere and its sky and ground

ratio, light and its flux density, and the observer's eye. Because the observations are of different parameters by day and by night and are individual valuations, they are not homogeneous with most test data

Visibility data are generally collected during tests. In the absence of definitive measurements equivalent to the sensory observations of visibility, these observations are perforce used along with attenuation measurements in evaluating various EO systems. For example, visibility observations are used in the appraisal of detection and identification ranges and spatial resolution in reconnaissance systems (IR, television, and laser) and strike systems (IR, television, laser illuminator, and laser range) as well as in the study of the performance of missile sensors. Visibility data often are compared (sometimes along with simultaneous measurements of contrast diminution and atmospheric transmittance) with the thermal resolution of IR reconnaissance and strike systems or with IR target temperature and recognition ranges.

3.3.3 Refractivity

Refractivity is used to determine environmental degradation of EO systems testing. Fluctuations in the refractive index structure (structure functions) disturb atmospheric electromagnetic wave propagation. Refractivity gradients pose special problems for EO testing, for example, "beam wander" and mirages.

3.3.4 Structure Functions

The temperature structure coefficient (C_T^2) provides a measure of the effects of small-scale turbulence on EO systems. Its use is generally confined to micrometeorological applications using a process computer which senses frequently (for example, every 1/2 second) and handles data on a statistical basis. C_T^2 is used in the determination of the refractive index structure coefficient (C_n^2).

Sometimes referred to as the optical turbulence coefficient or parameter, this parameter C_n^2 is a function of pressure, wind, and temperature and their gradients, temperature gradient being the dominant term. It may also be expressed in terms of a stability parameter such as Richardson number. It may be measured directly by ground or tower-based equipment consisting of fine-wire probes and u-v-w (orthogonal components of a three-dimensional wind field) anemometers, by a balloon-borne system, by aircraft-mounted sensors, or remotely by the acoustic sounder. A value of C_n^2 of the order of $5 \times 10^{14}\ m^{-2/3}$ represents moderate-to-severe optical turbulence. C_n^2 is also used to investigate the effect of small-scale turbulence on EO systems, especially the effects of optical scintillations.

3.3.5 Clouds

Cloud measurements are needed for correlation with observed signal-to-noise ratios (SNR) and IR returns. Clouds alter the SNR, which decreases the probability of EO detection of targets and generates false returns in the IR portion of the spectrum.

3.3.6 Aerosols

Measurements of atmospheric particle size and concentration and identification of aerosol constituents are used in the calculation of signal attenuation due to absorption and scattering. Atmospheric attenuation is required to determine acquisition and lock-on ranges and to determine guidance sensor tracking capability for varying atmospheric conditions.

3.3.7 Illumination

Measurements of predominant illumination and the level of illumination on a target are used to evaluate EO systems performance under varying conditions of natural illumination. Azimuth and elevation of illumination are also needed since the location of the source relative to the target and EO device affects the performance of EO systems. Generally, solar radiance is higher at angles near the sun's direction and lower at angles normal to that direction.

EO devices forming part of night vision systems are subject to an additional limitation on their performance; they are affected by moonlight producing an overall increased sky radiance and an increased path luminance between device and target. Because backward scatter of the moonlight is less than forward scatter, path luminance is reduced for a system with its back to the moon and target contrast is increased. If the EO system is looking "into the moon" or fairly close to the moon's direction, it observes little or no change in contrast transmission; but by virtue of the forward scatter of lunar radiation toward the device, the sensor suffers a loss of resolution which might be termed "moon-blindness." Nocturnal EO testing therefore requires a specification of three quantities (angular direction of illuminating source, sky radiance, and path luminance).

Figure 3-1 presents estimates of illumination levels on the surface of the earth as a function of solar altitude with and without clouds; position of the moon is also included.

3.4 EO METEOROLOGICAL SUPPORT SYSTEMS

Meteorological data instruments and collection systems need to be designed and acquired to provide EO systems engineers with those atmospheric data requirements generated by real-world test scenarios. Weather sensitivities are not the same for the different major EO weapons systems. The meteorological systems must be capable of acquiring, formatting, digitizing, averaging, processing, storing, and displaying data from a large variety of instruments and

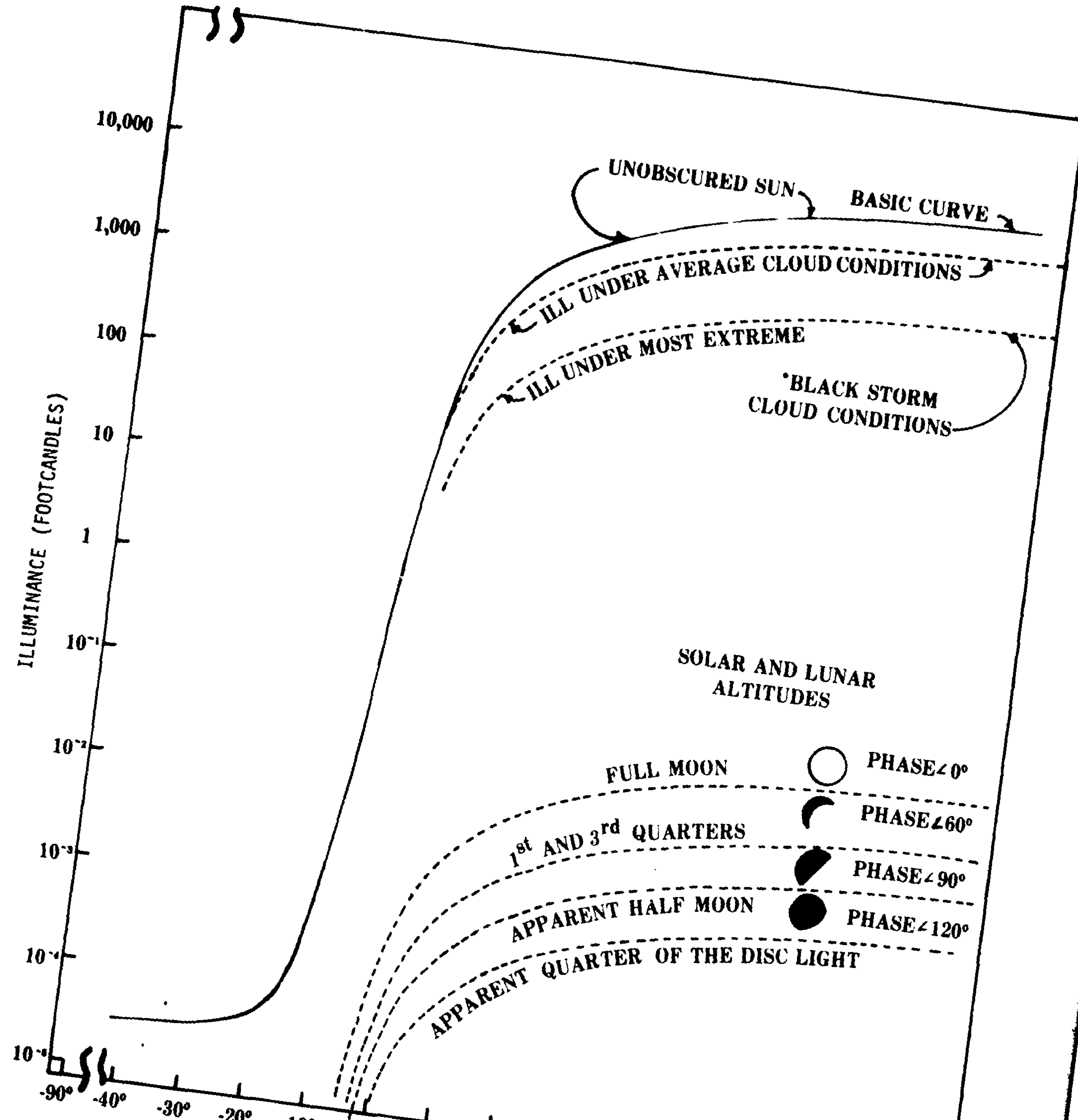

Figure 3-1. Natural Illuminance.

locations. Frequency of observations, sample rates, and types of measurements will change with the specific data requirements of the test, the location, and the weapons systems.

Also, differentiation must be made between the instrumentation needs of the researcher and designer and the tactical commander; for example, a very complex instrumentation system may be needed for research and design requirements, but a much more simplified system may be entirely suitable for tactical applications.

The EO meteorological support system must include the capability to process measurements of conventional meteorological quantities, micrometeorological parameters, optical parameters, atmospheric gases, and aerosols from standard and special-purpose instruments on the ground, on towers, and aloft on aircraft (including remotely piloted vehicles [RPV]), balloons, rockets, and parachutes. Instruments, microprocessors, minicomputers, recorders, data transmission devices and all ancillary hardware and software must be specified to provide an integrated support system.

3.5 WEATHER RELATED SUPPORT REQUIREMENTS

In addition to the atmospheric data gathered at the test site, the meteorologist requires information gathered over the larger area around the test site. This information is used for synoptic meteorology and forecast purposes. Climatological information and data analyses and distribution are also required.

3.5.1 Synoptic Meteorology

Synoptic meteorology is a record of general meteorological conditions over the test area in the form of synoptic surface and upper air charts. Analysis of these weather patterns provides a description of significant synoptic features occurring during the test. For example, air mass trajectories are considered by using data integrated from satellites, conventional weather observations, and other related information to interpret the sum total of atmospheric measurements and their effects on optical transmission.[32] [33] Also, the relationship between observed synoptic patterns and the various concurrent forms of aerosols and precipitation observed should be determined.

[32] J. Rosenthal et al, 1979, Marine/Continental History of Aerosols at San Nicolas Island During CEWCOM-78 and OSP III, TP-79-32 (Summary) and TP-79-33, Pacific Missile Test Center Technical Publications, Point Mugu, CA.

[33] T. E. Battalino et al, 1979, Air Mass Trajectory Analysis as an Aid in Distinguishing Marine from Continental Aerosol Disturbances at San Nicolas Island, IAORS Workshop in Atmospheric Aerosols, 6-8 November 1979, San Nicolas Island, CA.

3.5.2 Forecasts

There is a need at EO test sites for mission-tailored forecasts of basic atmospheric parameters for go/no-go decisions on test days. These forecasts are necessary to avoid costly multiple test support for EO weapons systems with critical atmospheric sensitivities or mandatory but infrequently occurring atmospheric phenomena. Prediction techniques are required for forecasting energy propagation through the atmosphere and for forecasting transport and diffusion of gases and particulates.

Synoptic meteorology-transmission relationships to be used in a predictive sense should also be considered. Such efforts are currently under development within the Navy's EOMET program.

3.5.3 Climatology

EO systems engineers and modelers also require climatological information. Meteorologists need to provide detailed inputs of average and extreme ranges of atmospheric variables affecting EO systems. Values of persistence, predictability, and climatological frequency of meteorological parameters are needed. With the assistance of climatological information, geographical areas and best time of year can be determined to take advantage of the maximum occurrence of adverse (but desirable for test scenario) meteorological phenomena.

Many areas of interest have no associated environmental observations or data to support the detailed accurate climatological studies or analyses required by the DOD.

A problem exists in adequately considering the geophysical influences on climate so that environmental information may be specified for intermediate locations by using the known climatological records from "nearby" observing sites.

The spatial, diurnal, and seasonal distribution of meteorological variables must be analyzed on the basis of the principal climate-forming factors, especially peculiarities of atmospheric circulation, from available point observation data. A need also exists to model and condense these available data sets of worldwide meteorological observations for computer storage so that answers to climatological questions can be provided routinely and rapidly in a near real-time, query response mode.

However, in addressing US Army needs for additional climatic data, Metzko[34] has suggested that until analyses are made to identify the best predictor(s) of EO system performance from optical measurements data already collected in such programs as OPAQUE, the US Air Force Atmospheric Effects Measurements

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[34]J. Metzko, 1980, "Army Needs for Additional Climatic Data," Coordinating Group Meeting (sponsored by ASL), 14 February 1980, Institute for Defense Analyses, Science and Technology Division, Arlington, VA

Program, and the US Navy Optical Signatures Program, there is no basis for requiring additional climatic data for estimating potential EO systems usage in any operational theater.

3.5.4 Data Analyses and Distribution

These support requirements provide meteorological data analyses, including tabular and graphic data presentation in reports as requried to meet test objectives and, after tests are completed, aid in the preparation of atmospheric aspects of test and evaluation reports.

3.6 METEOROLOGICAL TEST AND EVALUATION PLANS

Overall, the meteorological support plan needs to provide for:

Selecting test site and instrument configuration;

Selecting meteorological and optical quantities to be measured;

Determining frequency of observations and sample rates;

Determining type of instrumentation and data collection techniques;

Installing and calibrating instruments;

Analyzing data and preparing reports.

CHAPTER 4

THE OPERATIONAL TEST AND EVALUATION COMMUNITY

E. H. Holt and H. H. Monahan

4.1 INTRODUCTION

The essential uniqueness of an operational test, as distinguished from a developmental test, is that of the operational test players' uncertainty of the exact time and place of the critical activities of target acquisition and engagement taking place.[25] Test control is so designed that these activities can be reconstructed after the test; but only under special conditions can relative positions of the players be fixed before the test. Also, because of the constraints of maximum "reality" of testing, the instrumentation used must not obtrude on player actions.

4.2 ATMOSPHERIC DATA REQUIREMENTS

4.2.1 US Army OTEA Requirements

Three elements--the need for a bridge between the technical characteristics specified in table 4-1 and those of the tactical decision makers, the need for unobtrusive measurements, and player uncertainty--form a special and rather intractable set of measurement requirements.

The OTEA has requirements for operational testing of EO systems in a "dirty battlefield." The need for meteorological measurements is to provide correlative indicators of the transmissivity of the medium at the time when LOS exists. OTEA is currently exploring ways to measure transmissivity of the medium when target acquisition occurs with EO systems, but sees no feasible way of measuring transmissivity to targets in LOS but not acquired. When LOS does not exist between launch platform and target, such as with COPPERHEAD or HELLFIRE fired "over the hill," some operationally useful predictive method based on meteorological observation is needed to estimate the transmissivity of the medium along the predicted trajectory of the weapon.

Meteorological data of interest in EO operational testing require a high temporal resolution, that is, within a few minutes of the occurrence of an EO target acquisition or engagement activity--particularly where there is fog, smoke, haze, dust, rain, or snow. Since meteorological information is to be used primarily for correlation to actual performance of EO systems, the horizontal resolution of the measurement should be within a kilometer of the engagement activity. To be operationally useful, the meteorological correlates should be based on visibility measurements in the photopic and IR spectra, with measurement accuracy within ±20 percent of the true range.

The peculiarities of operational testing require that the measuring instrumentation be quite reliable and fairly simple to operate, since the processes of

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[25]Letter, 10 May 1979, US Army Operational Test and Evaluation Agency, CSTE-ED, subject: "Meteorological Data Requirements for Electro-Optical/Near Millimeter Wave Technology"

an operational test are characterized by continuity as contrasted to discrete events which happen at the convenience of the tester.

4.2.2 US Army CDEC

Given perfect atmospheric transmissivity and visibility between the player and the target, the player often neither sees nor acquires the target during its period of exposure. While this phenomenon is fairly well understood and reproducible test results can be obtained for equal conditions of player uncertainty as regards the time and place of target appearance, the effect of atmospheric obscurants is neither well understood nor predictable.

Love[35] has addressed the requirements of field experiments and force-on-force tests conducted under obscured conditions. He describes environmental requirements as being needed in the categories of:

Visibility

Weather

Obscuration

The primary data requirement in the first category is the time history of mutual player visibility. These data are essential to evaluate the interactions between player elements and address such questions as "could the threat neutralize friendly weapons by deploying obscurants at crucial times?" or "could friendly weapons take advantage of naturally occurring 'windows' in deployed smoke?" Specific visibility requirements are given in table 4-1.[36]

In addition to the primary data requirements in table 4-1, there is a general need for documentary data in the second category concerning the weather conditions under which a test or experiment is conducted. The weather data requirements in table 4-2 are intended to sufficiently document general weather data requirements. Other atmospheric data in tables 4-1, 4-2, and 4-3 are also necessary to model visibility and estimate mutual player visibility if direct measurement is not possible.

Obscuration data in the third category may be required by test proponents such as modelers and system developers if needed to evaluate systems degradation versus the degree of obscuration. An estimate of these potential requirements is provided in table 4-3, the data requirements itemized are potentially necessary to determine the intervening obscuration condition between players. The space-time distribution of a given obscurant condition can be estimated by using a smoke obscuration model or can be measured directly with instrumentation, as long as the specifications are met.

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[35]G. G. Love, 1979, "Field Test Requirements," Atmospheric Data Requirements Workshop, 13-14 February 1979, ASL Internal Report, J. T. Hall, ed, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[36]G. G. Love, 1980, Atmospheric Data Requirements for Battlefield Obscuration Applications, Coordinating Group Meeting, 14 February 1980, US Army Combat Development Experimentation Command, Fort Ord, CA

TABLE 4-1. VISIBILITY DATA REQUIREMENTS[36]

Requirement	Specification
Coverage	7 x 7 km
Mutual player visibility†	Yes/no*
Time of occurrence	±1 s
Duration of visibility	±2 s or ±5% of total period

†At the wavelength of the player system

*Decision should be correct ≥90% of the time

TABLE 4-2. WEATHER DATA REQUIREMENTS[36]

Requirement	Specification	Frequency
Ambient temperature	±1°F from -20° to 130°F	15-min intervals
Temperature gradient	±10% of true	15-min intervals
Relative humidity	±1% from 0 to 100%	15-min intervals
Barometric pressure	±1 mmHg from 600 to 800 mmHg	15-min intervals
Windspeed	±1 m/s from calm to 25 m/s	Per minute
Windspeed gradient	±10% of true	Per minute
Wind direction	±1 from 1 to 360 deg	Per minute
Precipitation	±0.02 in/h from none to 1/2 in/h	15-min intervals
Visibility	±10% from 100 m to 50 km	15-min intervals
Cloud cover	Nearest 5% from none to 100%	15-min intervals

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[36]G. G. Love, 1980, Atmospheric Data Requirements for Battlefield Obscuration Applications, Coordinating Group Meeting, 14 February 1980, US Army Combat Development Experimentation Command, Fort Ord, CA

TABLE 4-3. OBSCURATION DATA REQUIREMENTS[36]

Requirement	Specification
Type of obscurant	Relative concentration
Fog, haze, precipitation, dust, smoke, artillery blast	
Transmission along LOS	±10% of true
Wavelength bands	0.4μm - 0.7μm 3.6μm - 4μm 8μm - 14μm
Time - space - density,	90% reliability
Contours	
Discrete levels	10
(X, Y, Z) grid	As fine as 5 m
Time grid	As fine as 1 s
Coverage	1 x 3 km

[36]G. G. Love, 1980, Atmospheric Data Requirements for Battlefield Obscuration Applications, Coordinating Group Meeting, 14 February 1980, US Army Combat Development Experimentation Command, Fort Ord, CA

CHAPTER 5

COMBAT SIMULATION AND WAR GAME PLAYERS

E. H. Holt and H. H. Monahan

5.1 INTRODUCTION

Weather is now being used with increasing frequency to add more realism to weather sensitive simulations and modeling efforts involving military decision making.

To date, much of the meteorological support to Army combat simulations and war gaming activities has been based on conventional climatology records and "canned" weather data for event-oriented models in the manual mode.

5.2 ATMOSPHERIC DATA REQUIREMENTS

As combat simulations and war gaming become more complex and sophisticated, they will require correlated data fields not normally associated with conventional climatology and the aviation-oriented operational data bases now utilized, for example, water vapor distribution, liquid water distribution, instantaneous rainfall rates, solar illumination, refractive index, thermal background radiation, and dynamic cloud-free LOS.

5.2.1 US Army Concepts Analysis Agency Requirements

Hock[37] has stressed the increasing utility of combat simulations (described in table 5-1) by the US Army Concepts Analysis Agency (CAA) in support of DOD military decision making. Analyses of current capabilities (and future requirements) of weapon and support systems are becoming increasingly irreplaceable by conventional test and evaluation procedures due to: (1) the complexity of modern weapons and support systems with associated long lead time development and unpredictable synergistic behavior, (2) lethality of modern weapons, and (3) the unprecedented cost of modern systems.

Hock[38] has also shown a hierarchy of Army combat simulations requiring environmental data support (table 5-2) and has identified micrometeorological data requirements for detailed combat simulation studies by CAA (table 5-3).

Weather effects data, that is, "dynamic weather scenarios," for the CAA models are being provided by the ASL. These scenarios are realistic hour-by-hour syntheses of small-scale weather conditions that are based on climatological data, synoptic weather patterns, and topographic effects.

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[37]H. E. Hock, 1979, "Aerosol Effects on Combat Effectiveness and Implications," Atmospheric Data Requirements Workshop, 13-14 February 1979, ASL Internal Report, J. T. Hall, ed, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[38]H. E. Hock, 1979, Briefing, Atmospheric Data Requirements for Combat Simulations, US Army Concepts Analysis Agency, Bethesda, MD

TABLE 5-1. GENERIC HIERARCHY OF COMBAT SIMULATIONS

Mainstream

Campaign (many systems aggregated at theater level)

↑

Battle (different systems in multiple opposition against different targets)

↑

Many-on-many (similar systems in multiple opposition against similar targets)

↑

One-on-one (systems in single opposition against similar targets)

↑

System (single system capabilities)

TABLE 5-2. ARMY HIERARCHY OF COMBAT SIMULATIONS

Theater-Level (CEM, IDAGAM, etc.)

-- Force structuring or support requirements
-- Course environmental influences modeled

Percent of time close air support available
Percent of time selected systems inoperable

Division-Level (DIVLEV, etc.)

-- Large echelon combat strength determination
-- Fine resolution environmental data required

Two-hour occurrence statistics for micrometeorology
Likelihood of occurrence of severe effects

Battalion-Level (AMSWAG, CARMONETTE, etc.)

-- Force mix analysis
-- Detailed micrometeorology data required

TABLE 5-3. MICROMETEOROLOGY REQUIRED FOR DETAILED SIMULATIONS

Combined Conditions Existing over Combat Area
-- Visibility
-- Light level; sky over ground brightness ratio
-- Cloud cover specifics; stability category
-- Precipitation level
-- Inhomogeneities
Seasonal and Diurnal Frequency of Occurrence for Each Combination
Band Extinction Coefficients and Reasonable Bounds of Uncertainty for Each
-- Visible
-- S20 and S25
-- Silicon
-- Mid IR
-- Far IR

5.2.2 US Army Combined Arms Combat Developments Activity Requirements

Pickett[39] indicates that the US Army Combined Arms Combat Developments Activity (CACDA) is currently supporting two models that are used in force structure analyses and scenario development, that is, the JIFFY war game and the Division war game (DIVWAG). Both of these models have some representation of weather and its effects on weapons systems operating in a combined arms battle. CACDA is also developing a new Corps Battle Game (CBG) for application to scenario development.

The impact of weather on the battle is currently represented by these CACDA models in three areas:

a. Weather conditions producing degradation/enhancement on target acquisition devices;

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[39]H. K. Pickett, 1980, Atmospheric Data Requirements for Battlefield Obscuration Applications, Coordinating Group Meeting, 14 February 1980, US Army Combined Arms Combat Developments Activity, Fort Leavenworth, KS

b. Weather conditions degrading the guidance systems of certain munitions (such as, TOW, COPPERHEAD, HELLFIRE); and

c. Weather conditions producing degradation or enhancement on vehicular rates of advance.

Weather effects data over a division for a 3-day period are provided by the US Air Force Air Weather Service. Data describing visibility range, temperature, and humidity are input to the EOSAEL routines. The LOWTRAN and GAP modules producing atmospheric transmission data are currently the only EOSAEL routines employed by CACDA. Work is ongoing to update the data base describing transmission in smoke and dust using the SMOKE and DRTRAN routines. The transmission data are combined with target signature and sensor response data to produce probabilities of detection for targets at various ranges. These probabilities are used in CACDA war games to describe open fire and engagement ranges. The transmission data are also combined with data describing the minimum energy thresholds for missile tracker systems to function against targets at various ranges. The resulting data, in the form of probability of missile abort, are used in the war games to represent the effectiveness of TOW, HELLFIRE, and COPPERHEAD under conditions described by the weather scenario.

Parameters that describe the play of changing weather conditions and the constraints of each CACDA model are shown in table 5-4. Weather conditions are assumed to be homogeneous throughout each weather cell in the terrain area considered by each of the models.

TABLE 5-4. WEATHER PARAMETERS NEEDED FOR CACDA WAR GAMES

Windspeed (knots) and wind direction (degrees)
Cloud cover (%)
Horizontal visibility range (kilometers)
Temperature (surface °C)
Dew point (°C)
Pasquill category
Relative humidity (%)
Pressure (millibars)
Temperature gradient (°C per meter)
Rain rate (millimeters per hour)
Cloud ceiling (kilometers)
Cumulative precipitation last 24 hours (centimeters)

CACDA Model Constraints

	Terrain Area (km x km)	Max Number of Weather Cells	Gaming Periods (h) Intermediate	Gaming Periods (h) Total
JIFFY	150 x 200	8	2	72
DIVWAG	30 x 80	9	1	72
CBG*	200 x 200	20	1	72

*All constraints for CBG are estimated. Model is currently in design phase.

5.3 ANTICIPATED FUTURE WEATHER REQUIREMENTS

To date, weather support methods have been limited by available elements of the operational data base and require extensive automated data processing capability and time.

Future weather requirements will likely be met through the development of a synthetic digital weather data base with the developed algorithms being verified against samples of real data, thereby providing credibility in the simulated weather data.[40]

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[40] D. Y. Macy, 1978, Trip Report - Air Weather Service Simulation Conference, Scott Air Force Base, IL, 10-12 October 1978

CHAPTER 6

THE NEEDS OF TACTICAL DECISION MAKERS AND TROOP TRAINERS

E. J. Fawbush, E. H. Holt, and H. H. Monahan

6.1 CLIMATE AND WEATHER EFFECTS ON MILITARY OPERATIONS

Climate and weather have a significant effect on all types of military operations. Weather affects observation, trafficability, control, performance of personnel, functioning of materiel, air support, and the range and effects of weapons. As with terrain, the commander seeks to take advantage of climate and weather in developing and applying combat power in the pursuit of his objectives.

One example in the Korean War is the timing of Red Chinese and North Korean major attacks in front of oncoming Arctic cold fronts, forcing United Nations Command (UNC) counterattacks to be conducted facing high winds, snowstorms, and extremely cold temperatures after frontal passage. Another example, also in the Korean War, is the habitual North Korean timing of ground assaults in periods of poor flying weather to negate UNC air superiority. In the Vietnam War, North Vietnamese forces also often took advantage of low ceiling and poor visibility to initiate ground attacks. Similarly, the German Army Ardennes offensive in December 1944 was timed to coincide with a period of poor flying weather because of allied air superiority.[41]

An event, seldom referenced, took place during World War II which saw the Japanese evacuate their forces from the island of Kiska in the Aleutian chain under the cover of persistent surface based clouds which maintained visibility at zero over a period of several days duration. To attempt this operation when the island was under near continuous surveillance by sea and air forces required an extremely excellent prediction of meteorological events for periods of several days. The success of the operation is evidence that the Japanese meteorologists were quite accurate in selecting the proper time period for the execution of the evacuation. The weather conditions provided a security blanket under which the entire garrison was evacuated and escaped without being detected by allied forces.

Commanders have become increasingly aware of the importance of the role of weather in tactical operations and have taken actions which express the need for more adequate weather information and improved knowledge of how such information may be most advantageously utilized.

An example is found in the debriefing report of a senior officer after service in Vietnam. To provide a continuous weather profile of the division area of operation, the division pathfinders were trained by US Air Force Weather personnel in the fundamentals of weather observation and reporting. A weather reporting net was established through the S2, 101st Aviation Group (combat, air mobile), controlling headquarters for the pathfinder elements, to the G2

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[41] J. Metzko and H. Hidalgo, 1979, Weather Information and Tactical Army Activities, Institute for Defense Analyses, Science and Technology Division, Arlington, VA

weather office. Pathfinders stationed on each firebase reported hourly the existing weather conditions at their respective locations throughout the division area of operation. On marginal weather days this system was augmented by weather check aircraft launched by the assault helicopter battalions and the air cavalry squadrons to check their areas of operation. Since current weather information was provided to aviators, the number of aircraft operating in marginal weather was controlled, reducing the probability of midair collisions.[42]

6.2 QUALITATIVE DESCRIPTION OF OBSCURATION FACTORS ON THE BATTLEFIELD[43]

The variability of the natural environment strongly affects the performance of EO weapons systems and imaging systems. During the Vietnam action, it was stated that the "smart" bombs, that is, the EO weapons, were "smart" only when used in noninterfering weather conditions--meaning no obscuration present.[44] Kays et al[43] have provided a framework for describing obscuration on the battlefield and have compiled specific information relating to central Europe. Obscuration factors are classified as clear atmosphere, natural obscurants, battlefield obscurants, and land/air interface. The clear atmosphere involves effects on EO systems arising from the absorption and scattering of electromagnetic energy by atmospheric gases. Water vapor has a dominant effect in the IR portion of the spectrum. Natural obscurants involve wet aerosols (including clouds and fog), dry aerosols, and all types of precipitation. The climatology of these quantities is needed for the theater of operations and is related to the principal air masses which invade the region. Battlefield obscurants are classed as intentional (smoke) and unintentional. Unintentional obscurants include dust from explosions and vehicular traffic; gases from gunfire and vehicle emissions; and heat plumes (affecting atmospheric turbulence) from fires involving vegetation, equipment, and other material.

The land/air interface influences the behavior of clouds, fog, wind, temperature, precipitation, and smoke. The stability category of the air is generally different in forested and open areas. Fog forms more readily in valleys, and precipitation favors the windward side of orographic features.

Many factors are important in quantitatively relating system prformance to specific environmental features. Most of these relationships between some measurable portions of the total propagation (for example, transmission, reflection, and scattering) and certain specific environmental variables (for example, water content, aerosol size distribution, and concentration) are now reasonably well understood.

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[42] J. J. Hennessey, 1971, Senior Officers Debriefing Report, 101st Airborne Division, (U), CONFIDENTIAL, May 1970-January 1971

[43] M. D. Kays et al, 1980, Qualitative Description of Obscuration Factors in Central Europe, ASL Monograph 4, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[44] J. F. Fuller, 1974, Weather and War, US Air Force Weather Service (MAC), Scott Air Force Base, IL

Failure of the tactical commander to anticipate and counteract the effects of the environment on EO weapons systems would result in weapons systems being seriously degraded, and under some conditions would result in exposing friendly forces to unwarranted risk and excessive casualties. Proper environmental threat anticipation can result in threat avoidance or the instigation of precautionary measures, such as tactics, to reduce the exposure caused by degraded system performance or to exploit the advantage gained by differentially improved system effectiveness.

It is also important to note that knowledge and information of the battlefield environment, combined with knowledge of opposing forces' weaponry, would assist battlefield commanders in making plans for the protection of troops and weapons systems.

6.3 ENVIRONMENTAL EFFECTS IN THE PRINCIPAL STAGES OF THE BATTLE

6.3.1 The Undisturbed Environment

The characteristics of the undisturbed environment are that it exists prior to and permits preparation for the battle. It may contain elements of a degraded environment, but not to the extent that preparation cannot progress. The environmental knowledge that is required in deployment intelligence consists of two primary categories: specifically, the fundamental flow regime and the moisture profile of the mesoscale region surrounding the potential battle area. Additional factors affecting illumination, for example, clouds, are also of interest. These data are to be used to describe the present situation (during planning stage--up to 24 hours before battle) and to forecast the immediate future status of the atmosphere above and surrounding the battle area. The acquisition of this knowledge requires the measurement or observation of the standard meteorological parameters used in forecasting, including multiple stations over the horizontal grid, as well as vertical structure data up through several kilometers altitude.

6.3.2 The Transition Stage

The transition stage can be important to the deployment planners for what it reveals. If the onset of the battle is represented by impact of explosive rounds, the movement of vehicles, the release of smoke, or any activity that generates dust, debris, smoke, or noise, then appropriate observations at that time (more so than measurements) can aid the planners in redeployment and operational strategies. For example, the observation of the movement of a discrete cloud of dust or smoke not only establishes the validity of the forecasts that were used in planning, but can also be used to adjust plans and operations within obscurants. Timely observations of the growth and movement of smoke and dust clouds made during the transition--before the battle area becomes "saturated" or totally obscured--thus become requirements for effective deployment planning.

6.3.3 The Environmentally Degraded Stage

The requirements for meteorological data within the degraded environment are those applicable to the "seeing" aspects (that is, transmissometers), to determine whether a munition can "see" the path it must travel, and those applicable to the determination of changes that will permit or require a redeployment (that is, when and where "clearing" will occur). Since transport and diffusion are governed by the dynamic state of the atmosphere, wind information is very critical.

6.4 CURRENT ARMY WEATHER INFORMATION SYSTEM DEFICIENCIES

Currently the Army's interest in meteorological support for tactical operations is centered around climatological studies, planning forecasts, and daily forecasts of meteorological events which have general application to field operations. Certain combat and combat support organizations with more specific meteorological requirements are responsible for their own requirements, that is, artillery, engineer, aviation, and medical units carrying out assigned missions. Current doctrine does not provide for routine dissemination of meteorological data to other potential military users.

Current meteorological observations are insufficient to provide increasing forecast resolution desired by successively lower level commands which are concerned with successively smaller areas of responsibility. An unknown degree of resolution and precision, and therefore usefulness of weather-information sensitive planning, is lost in transforming synoptic and large-mesh mesoscale forecasts to fine-mesh mesoscale forecasts for areas of interest without additional local area observations. To alleviate this problem, the US Army (Europe) has initiated a Forward Area Limited Observation Program (FALOP) involving minimally trained personnel (of intelligence sections in divisions and armored cavalry regiments) equipped to measure basic surface weather parameters, to provide additional observations to supplement Air Weather Service observations in the eastern parts of West Germany.[41]

Cundy[45] has indicated that the following atmospheric parameters (and accuracies) from the FALOP would likely be the only atmospheric intelligence available on the tactical battlefield during hostilities:

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[41] J. Metzko and H. Hidalgo, 1979, Weather Information and Tactical Army Activities, Institute for Defense Analyses, Science and Technology Division, Arlington, VA

[45] R. G. Cundy, 1980, Atmospheric Data Requirements for Battlefield Obscuration Applications, Coordinating Group Meeting, 14 February 1980, US Army Intelligence Center and School, Fort Huachuca, AZ

Atmospheric Parameters	Accuracy
Cloud cover	1/8 ths
Low cloud height	500 m
Visibility	100 m
Wind direction	20 deg
Windspeed	5 kn
Dry-bulb temperature	1°C
Wet-bulb temperature	1°C
Precipitation	Yes/no
Dry aerosols	Yes/no
Wet aerosols	Yes/no

Measurement frequency: 3 per day.

Space interval: 5 to 10 km.

It appears unlikely that additional atmospheric data would be collected to complement the current routine observations unless such measurements could significantly improve the deployment of weapons systems on the battlefield.

A reasonable alternative solution involves research, development, test and evaluation efforts that produce realistic correlation relationships between routinely collected atmospheric data available from the battlefield area and other environmental data affecting electromagnetic propagation that can be readily obtained during specialized experiments.

If environmental measurements equivalent to those stated for research, development, test and evaluation purposes are determined to be those which can assure effective weapons system employment in tactical operations or training, then it will be necessary to review the standard meteorological observation to determine changes and additions that will be needed. A review will also identify instrumentation requirements, both old and new, to obtain the required measurements.

6.5 ENVIRONMENTAL SUPPORT NEEDS FOR TRAINING AND TACTICAL EMPLOYMENT OF COMBAT FORCES

The first objective of field exercises is realism; the position here is that there are no essential differences between the environment which has to be characterized during field exercises and the situation in battle.

Rapid advancement in the development of weapons systems technology has brought about changes in the concepts of training and tactical employment of combat forces (and the essentials of combat support and combat service support) which have identified the need for environmental measurements over and beyond the standards now being followed. The need for enhanced meteorological measurements, to include measurements of the atmosphere composition and measurements with accuracies not now being obtained in the routine meteorological observations, has been emphasized by the EO community as, top priority requirements for the support of modern weapons systems development. Adequate weather assessment capabilities should provide measures of EO systems effectiveness as

a function of space and time in the natural environment. Environmental effects measurements should be provided to tactical forces as frequently as required, but at least once every 6 hours.

As a starting point for identifying a standard set of atmospheric parameters for the battlefield, TRADOC has identified categories (of atmospheric turbidity), degradation factors, and related atmospheric parameters which describe the "dirty battlefield" (table 6-1).

The alternative to the development of a complete EO environmental support system is a compromise involving the conversion of standard meteorological observations into forms of information for EO purposes. The visual portion of the meteorological observation, that is, clouds, hydrometeors, and lithometeors, would be elements requiring some form of conversion to be suitable for EO purposes. Under some circumstances it may be possible to reasonably estimate cloud distribution if the cloud is a single layer; however, complications can arise from low clouds over complicated terrain. The relationship between condensation particles and fog would be a very gross estimate.

In a tactical or training situation, there does not exist within the combat or combat support forces the capability to acquire and disseminate meteorological and environmental data and information. There is not a source in the tactical area which routinely acquires meteorological and environmental measurements or observations except for the artillery meteorological sections and the Air Force weather teams when deployed. It is true that some meteorological information is available from combat intelligence debriefings; however, because of the processing time, much of its value as real-time meteorological information is lost.

TABLE 6-1. DIRTY BATTLEFIELD DESCRIPTORS

ATMOSPHERIC DATA REQUIREMENTS DB CATEGORIES, DEGRADATION FACTORS, AND PARAMETERS

Category	Degradation Factor	Parameter
Precipitation	Rain Snow Hail Sleet Drizzle	Particle size/shape Frequency Duration Accumulation (cm) Intensity (mm/h) Concentration (gm/m^3) Visibility (km) Temperature (°C/°F) Humidity (relative/absolute) IR attenuation
Wet Aerosols	Fog Clouds Haze	Area (km^2) Height (m) Visibility (km) Frequency Duration Particle size/shape Liquid water content Total moisture content Frozen/unfrozen Chemical composition Vertical structure IR attenuation Concentration (g/m^3) Extinction coefficients Wavelength (m)
	Cloud Peculiar	Sky cover (1/8's) Ceiling height (m) Cloud-base height (m) Cloud-top height (m)
Dry Aerosols	Smoke	Air temperature (°C/°F) Cloud temperature (°C/°F) Burning rate (gm/min) Wind (m/min) Pasquill's stability categories (A-F) Relative humidity (percent) Diffusion rate (per min) Persistence (min) Visibility (km) Particle size/shape Chemical composition IR attenuation Extinction coefficient Wavelength (m) Atmospheric mixing depth (m) As applicable: round type round size number of rounds round frequency (per min)

CHAPTER 7

MINIMUM DATA REQUIREMENTS FOR ATMOSPHERIC EFFECTS ON EO SYSTEMS

J. T. Hall, M. G. Heaps, D. W. Hoock, and R. A. Sutherland

7.1 THE MINIMUM DATA REQUIREMENTS SET

The objective of this section is to provide a minimum data requirements (MDR) set which will satisfy the needs for determining environment effects on EO systems.

This MDR set will be necessarily limited to defining the atmospheric or environmental propagation path characteristics. Occasionally environment, for example, rain and snow, affects the target and background, but the effects are generally unique to the conditions of the measurement and sensor system. These effects may need special consideration in the form of esoteric measurements. The MDR objective will be accomplished by defining those elements which must be measured for different categories of propagation environments. The set called "fundamental" (table 7-1) are elements which should be measured for all propagation environments. The two additional categories needed to cover the total range of environmental effects will be entitled "adverse weather" and "battlefield induced contaminants (BIC)." For the purposes of this section, adverse weather will be defined as the inclusion of any particulate matter into what was a purely gaseous medium. The measured elements to be added to the fundamental set exemplify this definition. The BIC category elements provide for the introduction of nonatmospheric gases, particulates, and the movement or dissipation of these contaminants within the propagation environment. These three data sets will adequately describe the environment through which radiant energy peculiar to a sensor system must propagate. Each element of these sets should be measured independently, not derived from other set elements. The temporal and spatial requirements of each element are generally dictated by the needs of the model or experiment and are usually limited by instrumental or measurement capability. All set elements have temporal characteristics and most, depending on individual requirements, must be considered to have spatial variability. The quoted accuracies for each element will provide an estimate for both temporal and spatial considerations. The MDR set, along with units and accuracies, is given in table 7-1. This table also indicates which measured elements are necessary for each of the four generic sensor bands. Changes in accuracy requirements will be shown in each wavelength region where applicable.

7.2 ELEMENTS OF THE FUNDAMENTAL SET

7.2.1 Pressure

The influence of pressure on the propagation path is its effect upon the widths of the gaseous absorption lines. Since virtually all systems operate within gaseous absorption windows where the attenuation is due to line wing absorption, variation in the line wings due to pressure broadening changes must be considered.

TABLE 7-1. MINIMUM DATA REQUIREMENTS

Parameter	Units	Accuracy	Visibility	Near IR	Far IR	Near Millimeter
			Fundamental Set			
Pressure	Mbar	±1 mbar				
Temperature	°C	±0.5				
Absolute humidity	g/m^3	±0.1	±0.5			
Visibility	km	±10%				±20%
Global radiation	$Watts/m^2$	±10%				±20%
Turbulence (C_n)	$m^{-1/3}$	±10%				
Transmittance	—	±10%				
			Adverse Weather			
Fundamental set +						
Aerosol size distribution	$\#/m^3$ /µm	*			>0.2µm	>50µm
Aerosol concentration	g/m^3	0.01				
Aerosol type	Rain, fog, etc.					
Air mass type						
Precipitation rate	mm/h	10%				
			Battlefield Induced Contaminants			
Fundamental set +						
Adverse weather set +						
Wind (u, v, w)	m/s	0.5				
Temperature lapse rate	°C/m	0.1/10m				
Stability category	Pasquill					

*See Accuracy Statement paragraph 7.4

Pressure varies slowly over horizontal paths, but has significant vertical variation. Thus single measurements should be adequate for horizontal paths, but vertical or slant paths require additional measurement, or reliance on atmospheric models.

Measurement presents few problems since direct pressure sensors are available.

Accuracy quoted is easily obtained with standard instrumentation.

7.2.2 Temperature

Temperature influences are due to path thermal emission and the dependence of gaseous absorption line strengths and widths on temperature.

For horizontal paths, spatial variability may be due to boundary condition variations (roads or water below path); otherwise, only diurnal variations are important. Slant or vertical paths will require more extensive measurement, as temperatures vary vertically in a complex manner. Microvariability is discussed under turbulence (paragraph 7.2.6).

Direct sensors, such as thermocouples, are available for temperature measurement. The required accuracy is easily available.

7.2.3 Absolute Humidity

Water vapor contributes to the visible extinction through molecular scattering and is a dominant absorber in the IR and MM domains. The most fundamental parameter for describing water vapor is the absolute humidity. Subsidiary parameters are relative humidity and dew and frost point temperatures.

Water vapor can vary over time scales of several minutes to months. Large diurnal variations in concentration and variations with height are common.

Absolute humidity may be measured a number of ways by using: (1) dew-point sensors, (2) wet and dry bulb psychrometers, (3) relative humidity sensors, or (4) Lyman-alpha sensors (see turbulence). Generally the wet and dry bulb and relative humidity sensors are not sufficiently accurate, especially near saturation, nor do they maintain the necessary precision for measurements of propagation effects. The dew-point sensors have been found most satisfactory. For measurement of rapid variations, see turbulence (paragraph 7.2.6).

Accuracy requirements increase as wavelength increases, becoming most stringent on MM systems because of the relative contribution of water vapor to total extinction. The high accuracies required at the long wavelengths make the dew-point sensor necessary, but even then the accuracies desired are not attainable with this instrument. The Lyman-alpha sensor may be necessary for MM propagation measurements.

7.2.4 Visibility

Traditionally defined as the maximum visual range for distinguishing a standard optical target, visibility is used as an indicator of atmospheric extinction, σ_{vis}. Theory and experiment have shown that visual range, R_{vis}, may be simply related to σ_{vis} by $R_{vis} = 3.912/\sigma_{vis}$.

Variability: Visibility is fundamentally a path quantity measured over a length greater than the resulting visual range. Thus, it can vary on the scale of R_{vis}. This visual range variability is itself changing due to the fact that visual range is being inferred through equations similar to Koschmeider's by measuring R_{vis}, which can be a point measurement. Thus, R_{vis} as a point quantity may vary over scales much smaller than R_{vis} itself.

Measurement techniques may be separated by distinguishing between path and point techniques. Path methods include: (1) observers using a target range or (2) visual transmissometers. The first method requires the establishment of a target range near the test path, with targets of constant intrinsic radiance and angular size. This method is usually not feasible, and the second method, using visual transmissometers, is employed. Because visual range has traditionally been a path quantity, many prefer to use path measurements to infer it. Note that seldom, except in low visibility conditions, does the transmissometer path length correspond to the measured visual range. This measurement is really a hybrid of path and point techniques.

Point measurements generally use instruments which measure scattering in a small volume of air, such as nephelometers or forward scatter instruments, since scattering is the dominant visual extinction mechanism. The fluctuation of the visibility is then used to infer the statistical characterization of the visibility along the propagation path.

Accuracy is again dependent on whether a path or point measurement is used, as point measurements can only indicate statistical properties of the propagation path visual range. Accuracies quoted are easily attained by standard instrumentation.

7.2.5 Global Radiation (Solar Insolation)

The primary influence of the radiation field illuminating the propagation path is its contribution to the path radiance due to scattering. The radiation may also significantly affect background clutter and target radiance.

The most significant variation is due to the presence of clouds, both within the path itself as fog or cloud or above the path.

Specific requirements may cause the average hemispherical measurement of global radiation to be unsatisfactory, but for path characterization this measurement is sufficient. Consideration should be given to the wavelength of the measurement, broadband or either visual or infrared. Infrared values may be inferred from visual or broadband values, but direct measurements may be valuable for infrared systems tests. MM radiance effects are due predominately to atmospheric emission; thus this measurement is less important for those systems.

7.2.6 Turbulence

Turbulence is the uncorrelated variation of atmospheric conditions, occurring on short time scales. In the atmosphere, the turbulence frequencies vary from a few hundred hertz to tenths of a hertz.

The influences of turbulence on electromagnetic energy propagation are many. Some of these influences are: (1) scintillation of received power, (2) angle of arrival variations, (3) depolarization effects, and (4) frequency shifts. These effects are caused by turbulence-induced changes in the refractive index of the atmosphere. In practice, turbulence often provides the most significant system operating constraints. The parameters involved in this process are temperature and absolute humidity fluctuations.

Turbulence varies horizontally and vertically due to the effects of the earth boundary layer. Scale sizes are given in terms of the inner, l_0, and outer, L_0, scales which refer to the smallest and largest turbulent structures, respectively. The inner scale l_0 changes vary little spatially and temporally, being controlled by the viscosity of air. The outer scale L_0 is a boundary effect and thus changes significantly with altitude. Below altitudes of a few hundred meters, L_0 is very roughly comparable to the altitude, though this comparability should not be relied upon.

Measurement of turbulence involves the measurement of the fluctuations of the refractive index. Refractometers with short response times ($\leq$ 5 ms) can measure the power spectrum of the refractve index fluctuations directly and provide the most data. Scintillometers, operating usually in the visible, give a statistical measurement of the turbulence, thermal C_N. Theory, which works well in the visible, provides the basis for the interpretation of C_N. The index fluctuations due to temperature or humidity variations can also be measured directly. High-speed thermocouples can measure either the temperature variation spectrum or the temperature structure parameter C_T directly. This contribution dominates at all but MM wavelengths. In the MM domain, water vapor fluctuations cannot be ignored. Here, sensors measuring Lyman-alpha absorption over short paths (~ 1 cm) are used. These instruments are not widely used since they were developed only recently. As with the measurement of visibility, the question of using path or point measurements must be considered. Refractometers and scintillometers are path measuring instruments; the other instruments measure effects at one point.

Due to the difficulties of measurement, it is difficult to provide extremely accurate measurements of turbulence. In most cases, a statistical description of the turbulence is all that can reasonably be provided.

7.2.7 Transmittance

Transmittance (τ) is the quantitative determination of the ratio of IR intensity [watts $\cdot$ sr^{-1}] received (I) to that transmitted (I_0); that is, $\tau = I/I_0$ where $0 \leq \tau \leq 1$. This measurement may be done over any convenient path length (P). For a homogeneous medium the measured τ may be extrapolated to the transmittance value τ' for any desired path length (ℓ) by

$$\tau' = (\tau)^{\ell/P} .$$

It is desirable to keep the quantity ℓ/P as near 1 as possible.

For path lengths, ℓ[km], the extinction coefficient (k_e)[km^{-1}] may be determined from $\ell n\tau = k_e\ell$. This coefficient is a product of both absorption and scatter by atmospheric gases and aerosols. Necessarily, the combined sum of the percents of absorption, scattering, and transmittance must equal 100. The extinction coefficient is known to be strongly dependent on wavelength and bandwidth; therefore, both of these quantities must be compatible with the system under analysis.

The accuracy of this measurement should be at least $\pm 0.10(\tau)$.

The *normalized uncertainty in* k_e, *that is*, $\delta k_e/k_e$, *can be written as*

$$\frac{\delta k_e}{k_e} = \frac{\delta\tau/\tau}{k_e\ell} = \frac{\text{uncertainty in } \tau}{\text{optical depth}}$$

so that optical depths $\simeq$ or greater than unity are desirable.

7.3 ELEMENTS OF THE ADVERSE WEATHER SET

7.3.1 Particulate Type

The particulate type measurement would contain all information necessary to characterize the composition of the aerosol producing the adverse weather. For the problem at hand this information is necessary for the ultimate determination of the real and imaginary index of refraction. Further characterization would be the more generic descriptions such as rain, snow, haze, fog, or (blowing) dust. Characterization is necessary because of the ultimate need to determine absorption and scattering coefficients which require particle shape information as well as refractive indices. The particulate type measurement is exceedingly important in cases where directional information, including polarization, is desired. For this ultimate determination, particle bulk density (specific gravity) and particle size distribution (discussed in the following paragraph) are also required.

7.3.2 Particle Size Distribution

This measurement would contain all information necessary to determine the number of particles per unit volume per unit size interval N(r). The size

categorization is assumed to be sufficiently defined by radius and is strictly true only for spherical particles but is commonly assumed for irregular particles as well. Ramifications due to irregular shape would be known from the particle type information described in the preceding paragraph. The ultimate desire would be for an entire spectrum from ($o < \lambda < \infty$), which for practical purposes is impossible. The range limits and bin resolution important for scattering information are dominated by the wavelength requirements and thus vary depending upon the application. Usually particles of radius on the order of the wavelength of interest contribute most significantly to scattering, and accuracy requirements are most stringent here. Absorption on the other hand is less markedly influenced by particle size, being instead dominated by imaginary refractive index which is a function of wavelength. In general both absorption and scattering are significant in the real world; but the relative importance of either, for the reasons mentioned above, is a function of particle size and wavelength. For any number of reasons, particle counters (except for the simplest cases) seldom produce an absolute spectrum; therefore, aerosol concentration must be measured simultaneously.

7.3.3 Particulate Concentration

This element is the determination of the mass concentration of the aerosol in question given in units of grams per cubic meter. In the literature this concentration is sometimes referred to as mass loading. Measurement of particulate concentration is considered fundamental even though in theory the concentration could be obtained by integrating the absolute size spectrum when the particle shape and specific gravity are known. In many circumstances, particulate concentration is actually the only particulate measurement required because, given a particular aerosol type (rain, snow, etc.), the particle spectrum can sometimes be assumed from previous studies. In other cases particulate concentration is simply not important and need not be constantly redetermined.

7.3.4 Air Mass Type

For this determination, reference is made to the meteorological term which defines air mass type according to the geographical origin of the ambient air mass surrounding the experimental test area. This determination usually requires a synoptic study of global airflow since passage of the latest front. Specifically, the following commonly used designations are referred to:

a. Tropical

b. Polar

c. Sub Arctic

d. Midlatitude

(1) Continental (example, midlatitude continental)

(2) Maritime

(3) Rural

(4) Urban

The importance of this element for our minimum set lies in the experimental correlation of aerosol nuclei with origin of the air mass. From this knowledge many properties of the adverse weather aerosol can be inferred.

7.3.5 Precipitation Rate

Precipitation rate is a quantitative measure of the accumulation of (equivalent) liquid water per unit time given in units of millimeters per hour. This measurement is usually a highly variable quantity both temporally and spatially, and sampling densities are dependent upon application. Enough information is needed to characterize the entire optical path and for time scales on the order of the response time of the EO device being tested. Sufficient sampling densities are required to estimate the variability of the rate over the spatial and temporal extent of the experiment. Precipitation rates should be accompanied by subjective descriptions such as wet snow, dry snow, etc. For very heavy precipitation, accuracy requirements are usually diminished; but for very light precipitation, accuracy is of increased significance.

7.4 AEROSOL DISTRIBUTION ACCURACY REQUIREMENTS

The objective of the accuracy requirements is to provide insight into the effects of inaccurate aerosol size distribution measurements on calculated extinctions. It is a common practice to use these measured distributions to calculate extinction using Mie theory. The theory and computational procedures are known to be accurate, yet computed extinctions show large variations from the same measurement site. To determine the effects of uncertainties in measured distributions on the precision of the computed extinction values, we assume a two-parameter exponential aerosol distribution of the form

$$N(D) = N_0 e^{-\alpha D} ,$$

where

$D \equiv$ aerosol diameters

$\alpha \equiv$ shape constant > 0

$N_0 \equiv$ normalizing number density > 0

and do an error analysis.

This distribution is generally useful for describing large aerosol environments, that is, rain, etc. Since we are dealing with large aerosol, one can assume an extinction efficiency (Q_e) appropriate to the optical limit; that is, $Q_e = 2$. The computed extinction k_e is then

$$k_e = 2 \int_0^\infty N(D)\pi\left(\frac{D}{2}\right)^2 dD$$

$$= 3\pi \times 10^{-3} N_o \alpha^{-3} .$$

If we define a mean aerosol diameter $\overline{D}$ as

$$\overline{D} = \frac{\int_0^\infty D\, N(D)\, dD}{\int_0^\infty N(D)\, dD}$$

which gives for the assumed distribution

$$\overline{D} = \frac{1}{\alpha} , \qquad (1)$$

we can rewrite the extinction coefficient to be

$$k_e = 3\pi \times 10^{-3} N_o (\overline{D})^3 .$$

This expression yields the normalized uncertainty for extinction as

$$\frac{\delta k_e}{k_e} = 3 \frac{\delta \overline{D}}{\overline{D}} , \qquad (2)$$

where $\frac{\delta \overline{D}}{\overline{D}}$ is the normalized uncertainty in the mean aerosol diameter. This result shows that for a 10 percent uncertainty in measured mean aerosol diameter one could expect a 30 percent uncertainty in the extinction coefficient. From equation (1) and

$$N(D) = N_o e^{-D/\overline{D}} ,$$

the normalized uncertainty in the distribution is

$$\frac{\delta N(D)}{N(D)} = \left(\frac{D}{\overline{D}}\right) \frac{\delta \overline{D}}{\overline{D}} . \qquad (3)$$

Equations (2) and (3) give for the final result and again for the assumed distribution

$$\frac{\delta k_e}{k_e} = \left(\frac{3\overline{D}}{D}\right) \frac{\delta N(D)}{N(D)} .$$

This result shows the relationship of the D to $\overline{D}$ in effecting the uncertainty in the extinction coefficient; that is, D may vary an order of magnitude, or greater, either side of $\overline{D}$. For the case that $D \approx \overline{D}$ the extinction coefficient uncertainty is a factor of 3 greater than the uncertainty in the measured size distribution. Aerosol distributions are considered by some to have uncertainties of 100 percent, making the quantitative evaluation of the extinction coefficient questionable.

7.5 ELEMENTS OF THE BIC SET

7.5.1 Introduction

BIC include suspended smoke, dust and other aerosols, and particulates which enter the atmosphere through intentional or unavoidable release during battle. Early following release, BIC are characterized generally by a local source (smoke munition or generator, HE explosion, vehicle treads, burning debris, artillery fire, etc.) producing a cloud of more or less well defined extent that transports with the wind and undergoes diffusion in the cross-wind and vertical directions, small-scale turbulent mixing and possible buoyant rise limited by any inversion layer present.

Although it can be argued that measurements included under the fundamental and adverse weather sets will completely characterize BIC obscurant properties (for any particular situation) as the cloud passes through the LOS path, there are at least two reasons for performing the additional measurements listed under BIC in table 7-1. First, a localized, meandering cloud requires a dense spacing of samplers along a substantial length of the path to define the concentration at points across the cloud. Through careful measurements of wind, temperature lapse rate, and stability category, however, physical models may be applied or developed to provide estimates of concentration along the path, thus supporting or replacing dense sampler requirements. Second, these additional measurements aid in correlation between the effectiveness of a given BIC source and scenario and those meteorological elements having the greatest influence on downwind concentration. This correlation then allows for extrapolation to new scenarios and to expected frequency of meteorological conditions at new locations.

After some time span following release, the larger of the BIC particulates may settle out or be scavenged by terrain. The remaining long-term suspension spreads over a large area. At this point BIC ceases to be a local phenomena and can be considered as a component of haze or windborne dust contributing to the "fog of war" included under adverse weather.

7.5.2 Wind (u,v,w)

Ideally, wind measurements should completely define the conical field expanding downwind from a BIC source of known location and type to the LOS. The measurements should include three velocity components, for example, downwind (u), crosswind (v), and vertical (w), and sufficiently frequent samples to provide averages for short-scale fluctuations (~ 1 s), meander (~ 10 s), and

mean (~ 100 s) for each component and total windspeed. Realistically, however, such extensive wind field characterization represents too extreme a goal. The minimum acceptable wind measurement is at two heights for each component set u, v, and w at a single location close to that region where the cloud passes the LOS (and for times correlated to those of a test trial). Values are thus provided for the most common model requirements of windspeed, azimuth direction, gradients with height, and wind elevation. Profiles with time allow for detailed study of cloud motion as well as standard deviations. Measurement uncertainties need be no better than 0.1 m/s in speed and 2° in direction but should be no larger than 0.5 m/s and 10°. The uncertainty attainable influences the minimum allowable separation in height of measurements required for sufficiently accurate gradients. The directions chosen for u and v should be specified with respect to north or with respect to the direction of the LOS.

7.5.3 Temperature Lapse Rate

Lapse rate is required particularly under stable air conditions and when the cloud is buoyant, or when there is a low lying temperature inversion which restricts the vertical rise of the BIC cloud before it reaches the LOS. The minimum acceptable measurement is ambient air temperature at two heights (but preferably more) at the same location near the region of the path through which the cloud passes. Relative accuracy should be 0.1°C for a 10-m difference in height to provide an accurate lapse rate. The height of an inversion layer should be measured if it is low enough to affect cloud rise. Unless there is a significantly different lapse rate along the path (or over the time span of a test), measurement at the one location and time is sufficient.

7.5.4 Stability Category

Although not directly measurable, stability is a categorization of mechanical turbulence, temperature, and wind fluctuations and correlates with the rate at which a BIC cloud expands in height and width downwind. Although derived, and therefore not a truly independent element of the minimum data set, stability is included here because it does succinctly provide a quantity directly relatable to obscurant effectiveness and is required by most BIC models. Stability should be given in systems which are well known, such as those of Pasquill (categories A through G) or Smith (categories 1 through 7). Computation is based on windspeed and average global radiation during the test (or insolation and cloud cover or sensible heat flux) and, in some formalisms, is adjusted for terrain roughness.

Since BIC cover a wide range of natural and manufactured particulates and aerosols, and since measurement elements listed under BIC in table 7-1 relate to cloud growth and motion, one must include all wavelengths as requiring these measurements.

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ABBREVIATIONS AND ACRONYMS

AMSAA	Army Materiel Systems Analysis Agency
AMSWAG	AMSAA war game
ASL	Atmospheric Sciences Laboratory
AVRADCOM	Aviation Research and Development Command
BIC	battlefield induced contaminants
CAA	US Army Concepts Analysis Agency
CACDA	US Army Combined Arms Combat Developments Activity
CARMONETTE	Battalion war game
CBG	Corps Battle Game
CDEC	Combat Developments Experimentation Command
CEM	CAA combat effectiveness model
CM	countermeasures
C_n^2	refractive index structure coefficient
C_T^2	temperature structure coefficient
DARCOM	US Army Materiel Development and Readiness Command
DB	dirty battlefield
DIVLEV	Division level war game
DIVWAG	Division war game
DOD	Department of Defense
EO	electro-optical
EOMET	Electro-Optical Meteorology
EOSAEL	Electro-Optical Systems Atmospheric Effects Library
FALOP	Forward Area Limited Observation Program
FLIR	forward looking infrared
GAP	Grafenwöhr, Fort A. P. Hill extinction scaling model

IDAGAM	Institute for Defense Analyses war game
IR	infrared
JIFFY	JTCG (Joint Technical Coordinating Group) munitions effectiveness model
LDWSS	laser designator/weapons systems simulation
LOS	line of sight
LWC	liquid water content
MIRADCOM	Missile Research and Development Command
NMMW	near millimeter wave
NVEOL	Night Vision and Electro-Optics Laboratory
OPAQUE	optical atmospheric quantities in Europe
OTEA	Operational Test and Evaluation Agency
OUSDRE	Office of Under Secretary of Defense for Research and Engineering
PGM	precision guided munitions
RPV	remotely piloted vehicles
SNR	signal-to-noise ratio
TCG	Tactical Coordinating Group
UNC	United Nations Command

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